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**Research
Paper NE-536**

1983

Multivariate Regression Model for Predicting Lumber Grade Volumes of Northern Red Oak Sawlogs

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Abstract

A multivariate regression model was developed to predict green board-foot yields for the seven common factory lumber grades processed from northern red oak *(Quercus rubra* L.) factory grade logs. The model uses the standard log measurements of grade, scaling diameter, length, and percent defect. It was validated with an independent data set. The model can be modified to predict various combinations of lumber grades.

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Manuscript received for
publication 27 June 1983

Introduction

Tables for estimating northern red oak dry lumber grade yields from factory grade logs have been developed in the past (Hanks et al. 1980; Schroeder and Hanks 1967). These tables were developed to provide estimates of lumber grade yields and values for graded hardwood logs. The yields by lumber grade were expressed as a percentage of total dry lumber tally volume. To apply the percentages, an independent estimate of lumber tally volume was required, using an appropriate log rule and estimated mill overruns. The tables provide the means to calculate good estimates of log value, but are difficult to use in mill efficiency simulation and economic models. Most mill efficiency models also require estimates of green yields rather than dry yields so that in the analysis the drying process can be separated from the sawing process.

We have developed a multivariate regression equation for predicting green board-foot lumber grade yields that is easy to use with computer analysis techniques. This report does not supersede the previous reports. It provides a tool for analyzing log quality implications more efficiently in the manufacture of hardwood factory lumber.

Data

The logs used in this study were sawn at eight band sawmills located in four states — Virginia, West Virginia, North Carolina, and Tennessee. This data set is part of the data used in the study by Hanks et al. (1980).

Although many independent variables were originally recorded for each log, only four proved important for yield predictions:

1) Factory log grade, as defined by Rast et al. (1973);
2) Scaling diameter (D) of the small end of the log to the nearest inch
3) Log length (L) in feet
4) Percent defect (P) expressed in decimal form (Rast et al. 1973).

The lumber resulting from milling the logs was graded in the green condition by graders certified by the National Hardwood Lumber Association. The lumber grades used are listed below with their abbreviations:

Lumber Grade	*Abbreviation*
Firsts and Seconds	FAS
FAS one Face	F1F
Selects	SEL
One Common	1C
Two Common	2C
Three A Common	3A
Three B Common	3B

A data set of 1053 logs was used in developing the model. Table 1 presents the average log measurements by log grade.

Table 1.—Averages and ranges of the log measurements of the model development data set

Variable	Average	Minimum	Maximum	Standard deviation
		Log Grade 1 (325 logs)		
Scaling diameter (inches)	19.7	13.0	31.0	3.7
Length (feet)	14.1	10.0	17.0	2.2
Scalable defect (proportion)	0.04	0.00	0.36	0.06
		Log Grade 2 (435 logs)		
Scaling diameter	15.6	10.0	29.0	3.6
Length	12.6	8.0	16.9	2.5
Defect	0.07	0.00	0.42	0.09
		Log Grade 3 (293 logs)		
Scaling diameter	12.8	8.0	27.0	3.6
Length	11.9	8.0	16.8	2.6
Defect	0.08	0.00	0.59	0.10

Model Development

Multivariate regression analysis was appropriate for the data set since there were multiple dependent variables, seven lumber grade yields for each log. The model is of the general form

$$y = xB$$

where

y = a row vector of the seven lumber grade yields
x = a row vector of the independent variables
B = a matrix of coefficients determined by regression analysis.

Since log grade is a classification variable with three levels, dummy variables, G_1 and G_2 were used to account for lumber grade yield variations due to differences in log grades (Draper and Smith 1981). The different combinations of G_1 and G_2 for the three log grades are:

Log Grade	G_1	G_2
One	1	0
Two	0	1
Three	0	0.

A weighted regression model proposed by Bruce (1970) was expanded to include dummy variables and multiple yields. It had the form:

$$Y_i/(D^2L) = b_{i0} + b_{i1}/D + b_{i2}/D^2 + b_{i3}\cdot P + b_{i4}\cdot G_1 + b_{i5}\cdot G_1/D + b_{i6}\cdot G_1/D^2 + b_{i7}\cdot G_1\cdot P + b_{i8}\cdot G_2 + b_{i9}\cdot G_2/D + b_{i10}\cdot G_2/D^2 + b_{i11}\cdot G_2\cdot P$$

where

Y_i = green board foot volume for the *ith* lumber grade,
$i = 1, \ldots, 7$;
Y_i = FAS, . . ., 3B
D^2L = weighting variable
b_{ij} = coefficients determined by regression for the *ith* lumber grade and the *jth* independent variable.

This model resulted in logical predictions of green board-foot volumes for each lumber grade. Two of the dummy variables ($G1/D^2$ and $G2/D$) were not significant at the 0.05 level of significance. Therefore, the equation was reduced to the following form for testing (coefficients will be presented later):

$$Y_i/(D^2L) = b_{i0} + b_{i1}/D + b_{i2}/D^2 + b_{i3}\cdot P + b_{i4}\cdot G_1 + b_{i5}\cdot G_1/D + b_{i6}\cdot G_1\cdot P + b_{i7}\cdot G_2 + b_{i8}\cdot G_2/D_2 + b_{i9}\cdot G_2\cdot P. \quad (1)$$

Validation

The set of data from a ninth mill was excluded from the model development phase of the study and used as a validation data set. This set consisted of 98 logs. Averages of log measurements are listed in Table 2. The method used for testing the equation involves the calculation of coefficients for the proposed model based on the validation set (Seegrist 1975). These validation coefficients are then compared to the coefficients from the developed model. If there is no statistically significant difference between the two sets of coefficients based on the Wilks-Lambda statistic, the model has passed the validation test.

The Wilks-Lambda statistic resulting from the test was 0.89. Since this is larger than the critical value, 0.84, at the 0.05 level of significance, the hypothesis that there was no difference in the coefficients between the two data sets was not rejected; therefore, the model was validated.

Table 2.—Averages and ranges of the log measurements of the validation data set

Variable	Average	Minimum	Maximum	Standard deviation
		Log Grade 1 (26 logs)		
Scaling diameter (inches)	18.6	13.0	25.0	2.9
Length (feet)	13.4	10.0	15.0	1.4
Defect	0.07	0.00	0.24	0.7
		Log Grade 2 (40 logs)		
Scaling diameter	15.1	11.0	24.0	2.8
Length	13.1	8.1	17.4	2.2
Defect	0.05	0.00	0.20	0.06
		Log Grade 3 (32 logs)		
Scaling diameter	11.5	8.0	16.0	2.2
Length	11.6	8.0	16.7	2.5
Defect	0.06	0.00	0.27	0.06

Results

The regression was rerun using the data from all the mills. All of the coefficients were significantly different from zero at the 0.05 level, with an overall Wilks-Lambda statistic of 0.005, indicating a very good fit of the model. For use, the weighted model (1) is rewritten by multiplying both sides of the reduced equation by D^2L. The final equation is then of the form:

$$Y_i' = b_{i0}\cdot D^2L + b_{i1}\cdot D\cdot L + b_{i2}\cdot L + b_{i3}\cdot D^2\cdot L\cdot P + b_{i4}\cdot D^2\cdot L\cdot G_1 + b_{i5}\cdot D\cdot L\cdot G_1 + b_{i6}\cdot D^2\cdot L\cdot P\cdot G_1 + b_{i7}\cdot D^2\cdot L\cdot G_2 + b_{i8}\cdot L\cdot G_2 + b_{i9}\cdot D^2\cdot L\cdot P\cdot G_2 \quad (2)$$

The final coefficients from this pooled data set are listed in Table 3. A comparison of the actual and predicted average yields for the pooled data set is presented in Table 4.

To further simplify the model, the dummy variables for log grades can be eliminated, resulting in three separate equations for each lumber grade:

log grade 1, lumber grade i

$$Y_i = (b_{i0} + b_{i4})D^2\cdot L + (b_{i1} + b_{i5})D\cdot L + b_{i2}\cdot L + (b_{i3} + b_{i6})D^2\cdot L\cdot P$$

log grade 2, lumber grade i

$$Y_i = (b_{i0} + b_{i7})\cdot D^2\cdot L + b_{i1}\cdot D\cdot L + (b_{i2} + b_{i8})\cdot L + (b_{i3} + b_{i9})D^2\cdot L\cdot P$$

log grade 3, lumber grade i

$$Y_i = b_{i0}\cdot D^2\cdot L + b_{i1}\cdot D\cdot L + b_{i2}\cdot L + b_{i3}\cdot D^2\cdot L\cdot P.$$

Table 3.—Matrix of coefficients (b_{ij}) for the final model

Lumber grades		Independent variables (j)									
	(i)	D^2L	DL	L	D^2LP	D^2LG_1	DLG_1	D^2LPG_1	D^2LG_2	LG_2	D^2LPG_2
		0	1	2	3	4	5	6	7	8	9
FAS	1	0.0049	–0.0815	0.3414	–0.0006	0.0284	–0.2407	–0.0279	0.0058	–0.5122	–0.0071
F1F	2	0.0066	–0.1049	0.4188	–0.0010	0.0023	0.0403	0.0025	0.0028	–0.0873	–0.0070
SEL	3	0.0007	–0.0132	0.0894	0.0009	0.0012	–0.0086	–0.0015	–0.0002	0.1684	–0.0022
1C	4	0.0267	–0.3261	1.1441	–0.0066	–0.0107	0.1758	0.0190	0.0054	–0.1512	–0.0082
2C	5	–0.0028	0.4062	–2.4485	–0.0050	–0.0060	0.0213	0.0041	–0.0040	0.4528	0.0043
3A	6	–0.0011	0.1663	–0.1109	–0.0047	0.0004	–0.1081	0.0109	–0.0027	–0.2437	0.0083
3B	7	0.0053	–0.0226	0.2609	–0.0012	–0.0041	–0.0008	0.0025	–0.0034	0.0864	0.0056

Table 4.—Averages of actual and predicted green board-foot volumes for the pooled data set

Lumber grade	Log Grade 1		Log Grade 2		Log Grade 3	
	Actual	Predicted	Actual	Predicted	Actual	Predicted
FAS	97.2	94.5	15.3	14.7	1.9	1.9
F1F	38.0	38.5	12.3	12.2	2.7	2.8
SEL	6.5	6.2	2.2	2.2	0.7	0.7
1C	66.2	67.2	48.8	48.4	19.2	19.0
2C	34.1	34.3	32.8	32.6	26.6	25.9
3A	12.1	12.2	16.6	16.7	20.3	20.8
3B	4.1	4.1	6.9	7.0	10.1	10.6
Total	258.2	257.0	134.9	133.8	81.5	81.7

Table 5 is an example of the tabular volumes estimated from the multivariate model for grade 1 12-foot logs with 5 percent scalable defect. This table cannot be directly compared with the tables developed by Hanks et al. (1980) until the volumes are converted to percentages and green to dry degrade factors are applied.

By substituting the average log length and defect of the validation set (Table 2) into the final model (2), we can derive an estimate of total green board foot lumber tally by scaling diameter. The total lumber tally estimates from the model are plotted with the actual data from the validation set in Figures 1, 2, and 3. We also plotted the appropriate volumes from the net International 1/4-inch and Doyle log rules. The relationships between estimated lumber tally volume and the log rules are reasonable for an efficient band sawmill producing standard factory lumber.

One common way to judge the effectiveness of different quality standards is to compare their estimates of volume in an index lumber grade such as No. 1 Common and Better. In Figures 4, 5, and 6 the predicted volume of 1C and Better from the multivariate model is plotted over the actual validation data. There is a distinct and uniform difference among the three log grades.

Table 5.—Predicted green board-foot lumber grade yields (log grade 1, log length 12, defect 0.05)

Scaling diameter	Lumber grade						
	FAS	F1F	SEL	1C	2C	3A	3B
13	18	13	1	24	19	7	2
14	25	15	2	28	22	8	2
15	32	18	2	32	24	8	2
16	40	20	3	36	26	9	3
17	49	23	3	41	27	9	3
18	58	26	4	46	29	10	3
19	69	29	4	51	30	10	3
20	80	33	5	57	31	11	4
21	92	36	5	64	32	11	4
22	104	40	6	71	32	12	4
23	117	44	7	78	32	12	5
24	132	48	8	85	33	13	5
25	146	53	9	93	33	13	6
26	162	58	9	102	32	14	6
27	179	63	10	110	32	14	7
28	196	68	11	120	31	15	7
29	214	73	12	129	30	15	8
30	232	79	13	139	29	15	8

Applications

As shown in Figures 1, 2, and 3, the model provides good estimates of total green lumber tally volume. This eliminates the need to calculate log scale volume and overrun in some computer analysis applications. Sawmill managers with computer facilities may also use the model to predict expected total lumber tally volume and volume by lumber grade from a group of graded logs.

A multivariate model is flexible enough that appropriate lumber grade coefficients can be combined if some of the seven grades are not separated at a particular mill. For example, if No. 3 common (3C) lumber is not broken down into 3A and 3B lumber grades, the coefficients for 3A and 3B (rows 6 and 7 in Table 3) may be added together. This results in a 6 × 10 matrix of coefficients that predicts FAS, F1F, SEL, 1C, 2C, and 3C. The equation for predicting the volume of 3C lumber is then:

$$Y_6 + Y_7 = 0.0042(D^2 \cdot L) + 0.1437(D \cdot L) + 0.1500(L) - 0.0059(D^2 \cdot L \cdot P) - 0.0037(D^2 \cdot L \cdot G_1) - 0.1089(D \cdot L \cdot G_1) + 0.0134(D^2 \cdot L \cdot P \cdot G_1) - 0.0061(D^2 \cdot L \cdot G_2) - 0.1573(L \cdot G_2) + 0.0139(D^2 \cdot L \cdot P \cdot G_2).$$

As this equation illustrates, the same result can be obtained by predicting 3A and 3B lumber yields and adding these yields together to predict 3C lumber yield. The above methods can be used to predict other grade combinations such as 1C and better or F1F and better.

(text follows on page 11)

Figure 1.—Comparison of total board volume predicted by the model, and by two popular log rules, with the actual volume of validation data set (Log Grade 1).

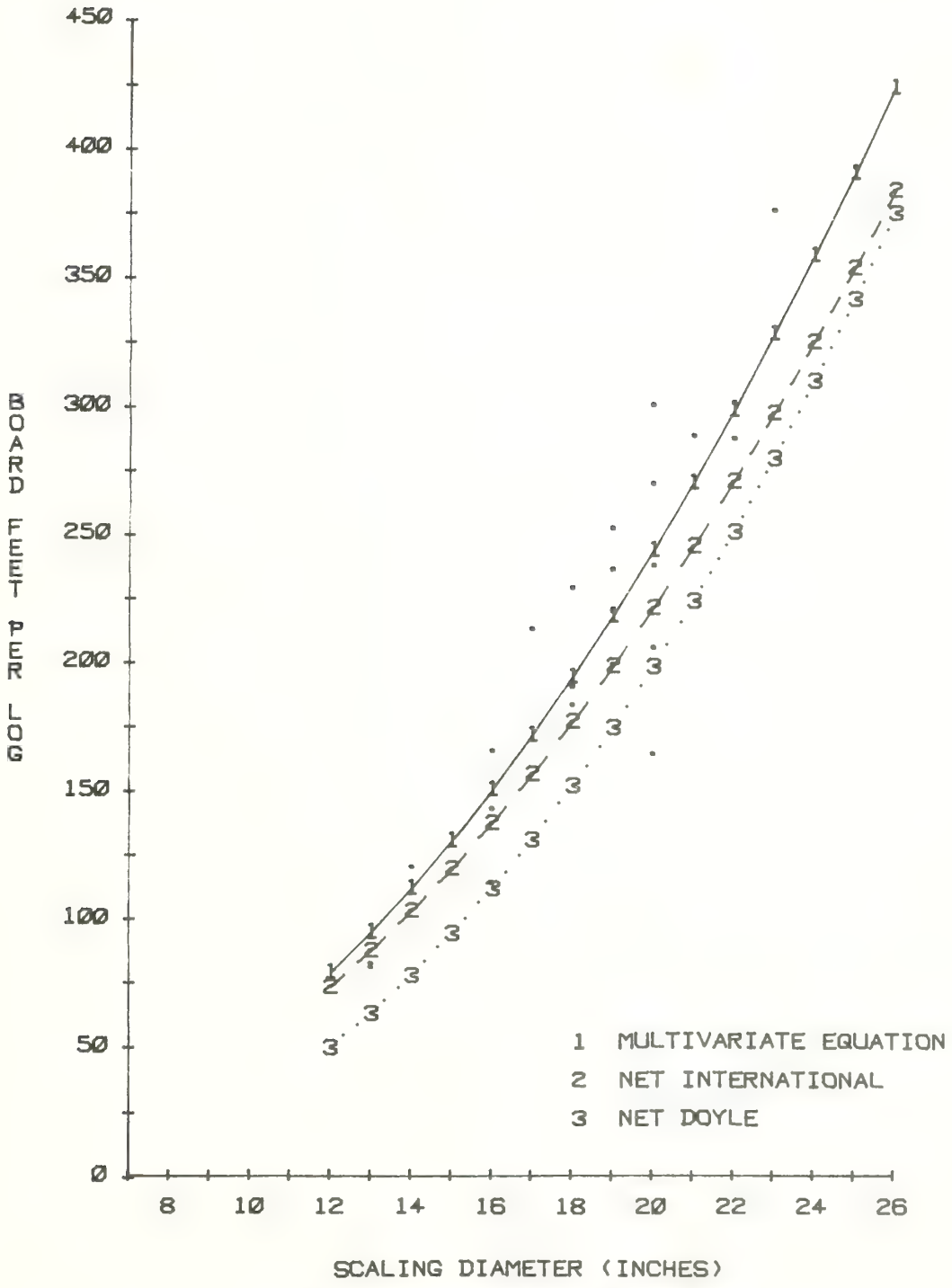

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Figure 2.—Comparison of total board volume predicted by the model, and by two popular log rules, with the actual volume of validation data set (Log Grade 2).

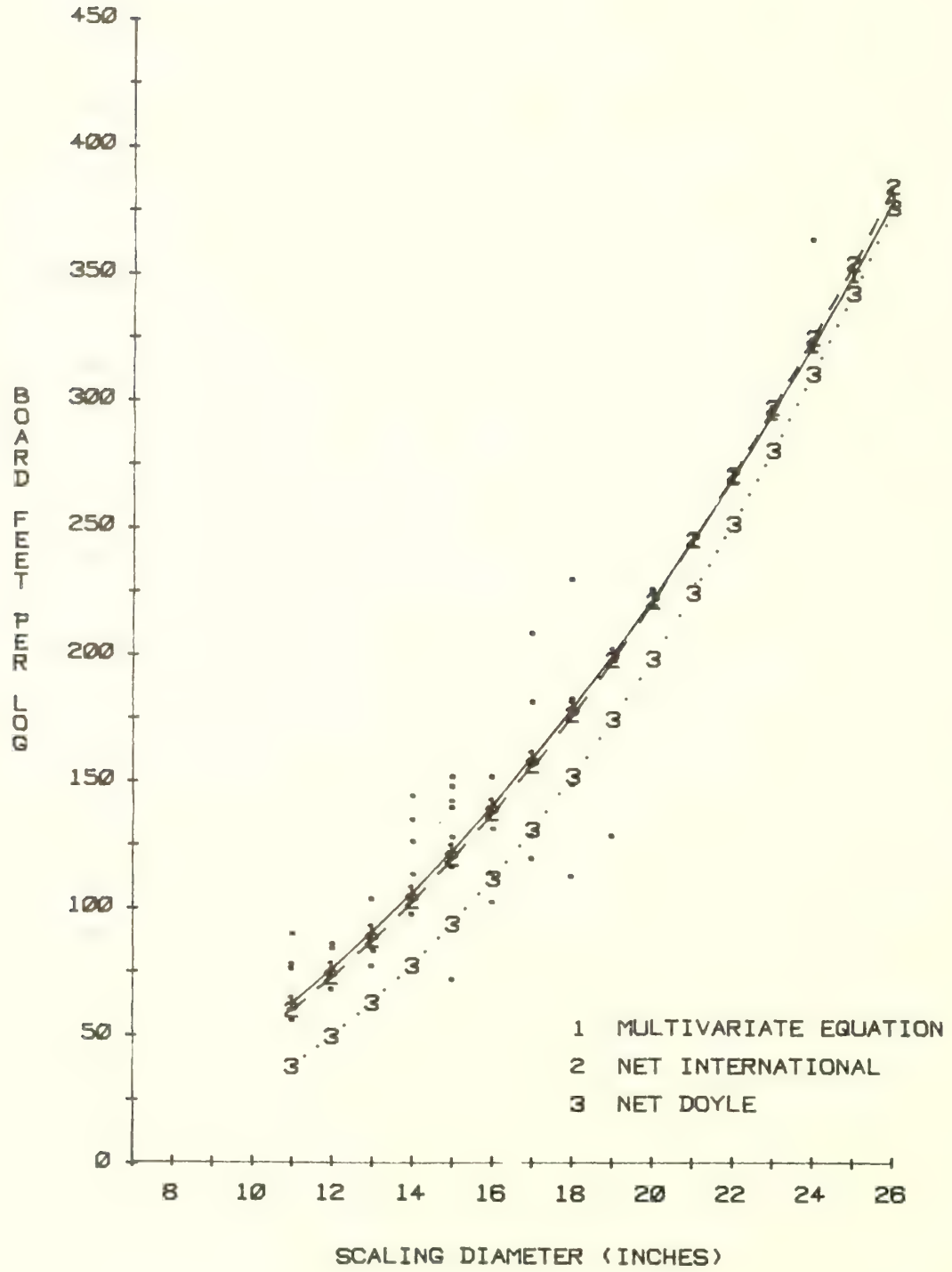


Figure 3.—Comparison of total board volume predicted by the model, and by two popular log rules, with the actual volume of validation data set (Log Grade 3).

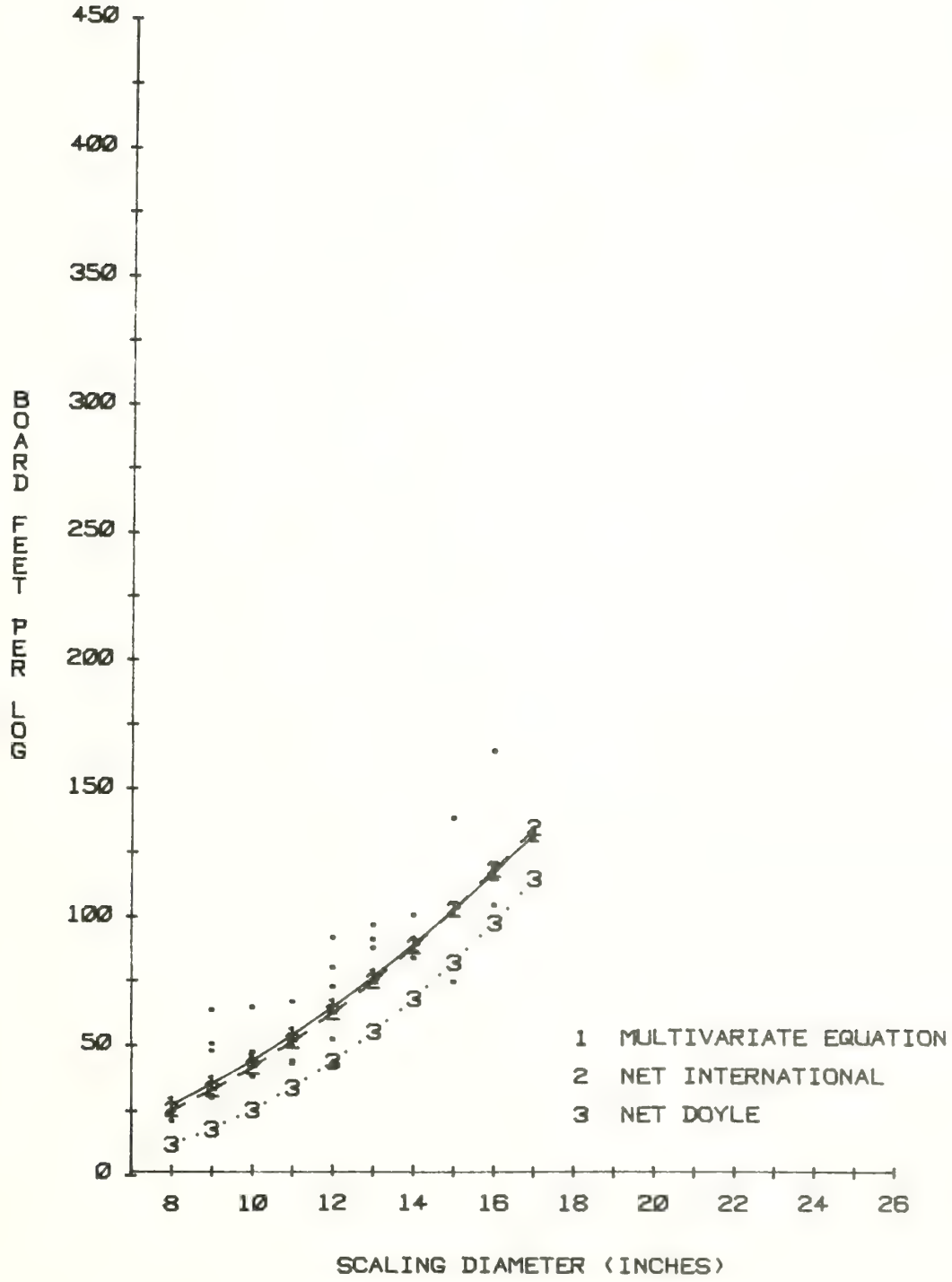


Figure 4.—Predicted volume of No. 1 Common and Better compared with actual volume of the validation data set (Log Grade 1).

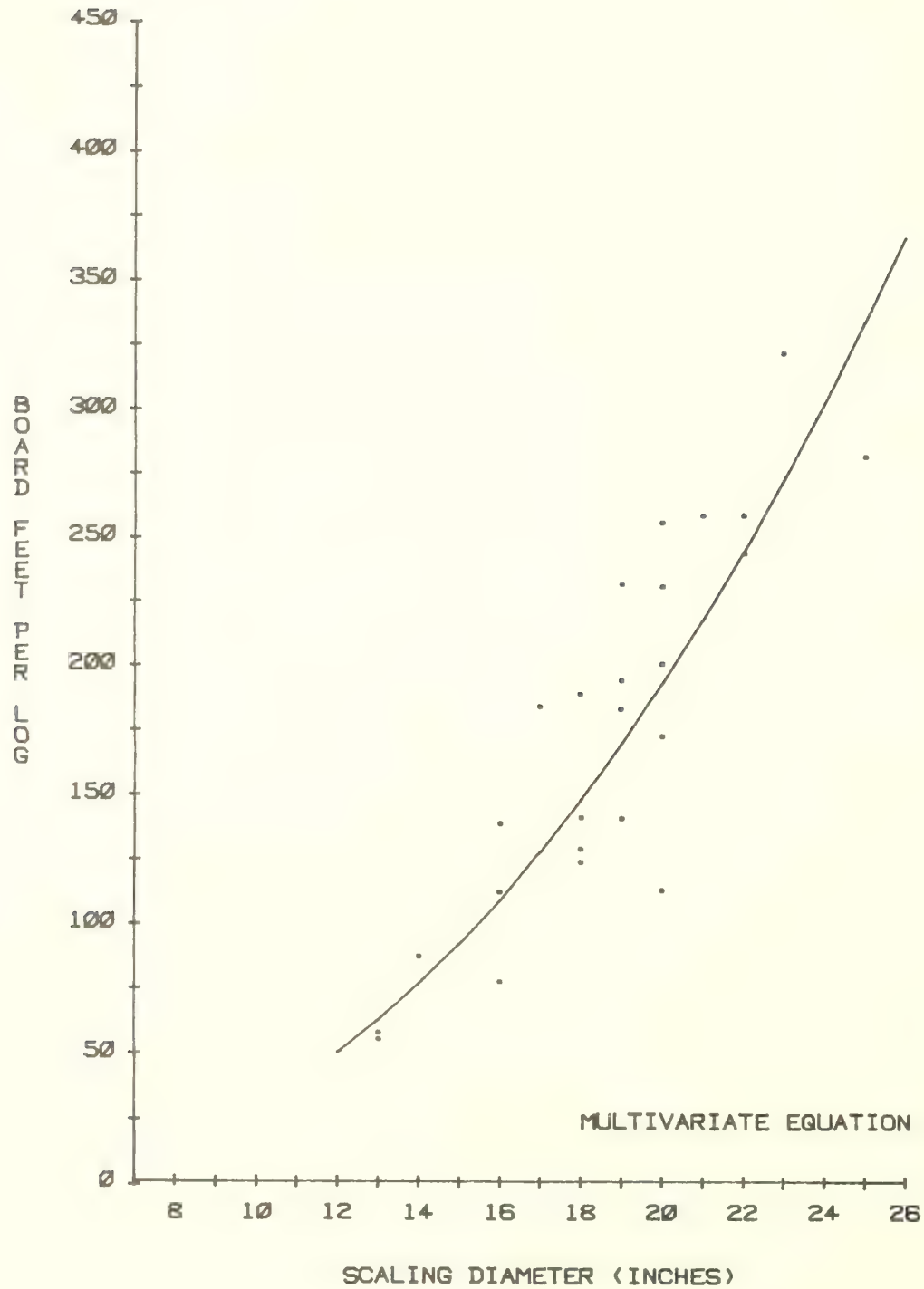


Figure 5.—Predicted volume of No. 1 Common and Better compared with actual volume of the validation data set (Log Grade 2).

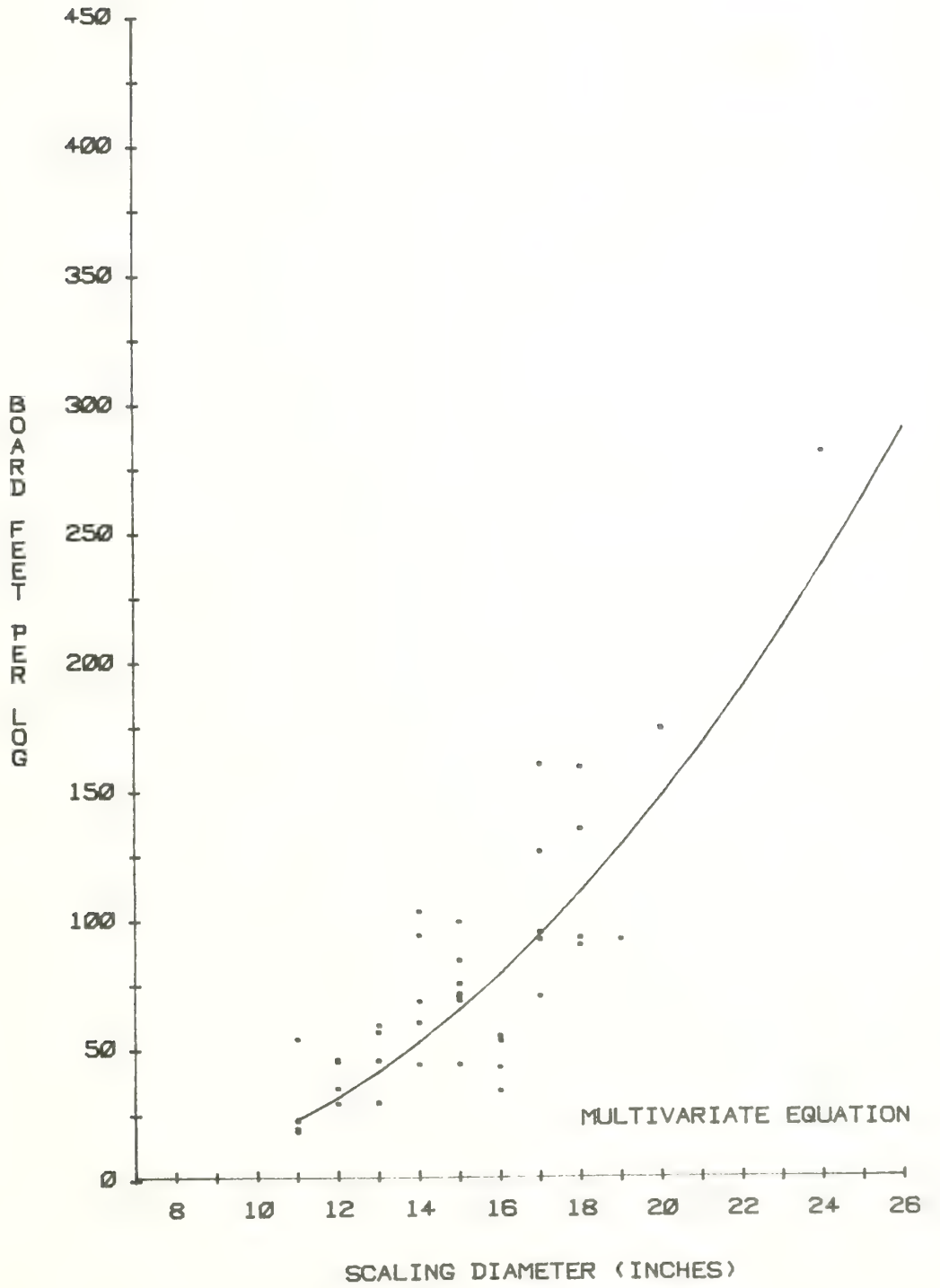
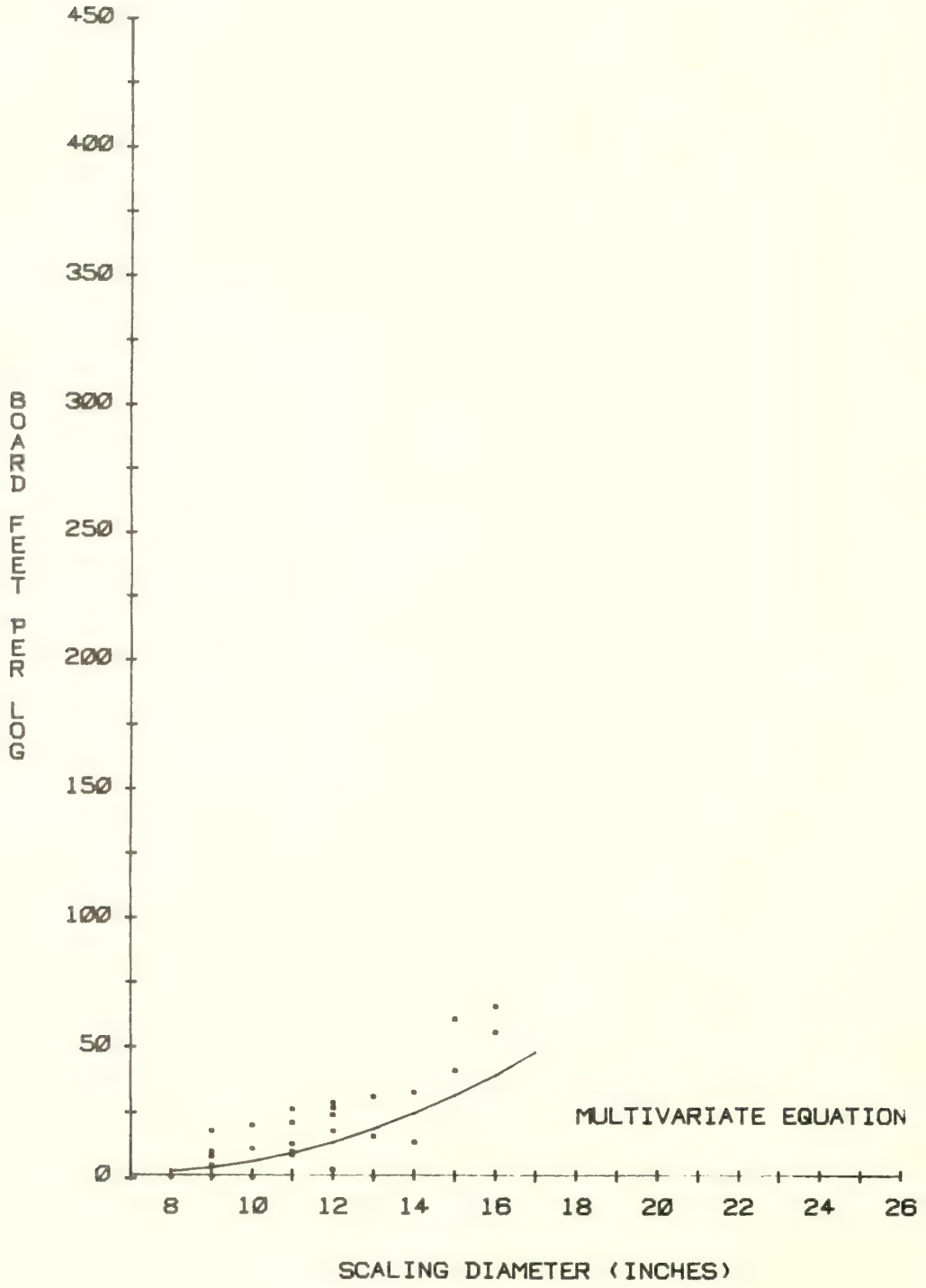


Figure 6.—Predicted volume of No. 1 Common and Better compared with actual volume of the validation data set (Log Grade 3).



The examples point out another aspect of the model's flexibility. It can be used as a single large matrix equation to predict board-foot volumes of all seven lumber grades simultaneously for any group of factory grade logs. Only log grade, diameter, length, and percent defect are needed to solve the equations. Because there are a large number of coefficients in the complete model, at least a minicomputer with substantial memory and matrix algebra functions is necessary to solve the equations efficiently. The model can also be divided into seven separate equations, one for each lumber grade, and solved in stepwise fashion on smaller microcomputers. Finally, any number of the seven equations could be combined into broader product classes by adding the appropriate coefficients. These combined equations could be solved by some programmable hand-held calculators.

Although this model was developed for northern red oak sawed in band sawmills, it may be suitable for related species or circular sawmills if the proper conversions are applied. The model is presently being tested on other species.

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A multivariate regression model was developed to predict green board-foot yields for the seven common lumber grades processed from northern red oak factory logs. The model may be modified to predict various combinations of lumber grades.

ODC 832.15—525.1-853

Keywords: Log quality; log grades; end product yields

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Research Paper NE-537

1983

Skidder Load Capacity and Fuel Consumption HP-41C Program

Ross A. Phillips

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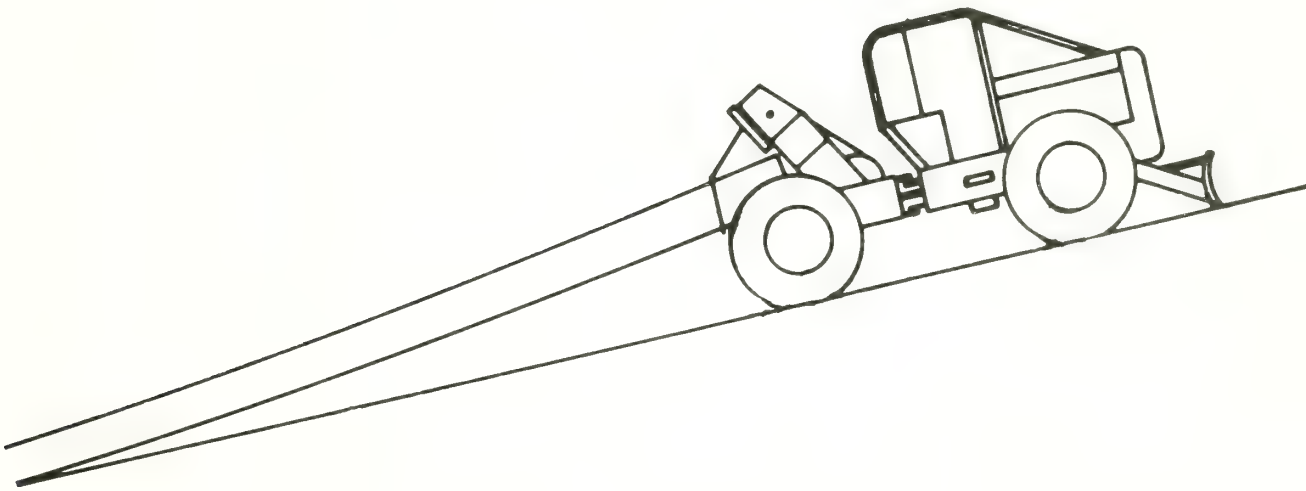

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Manuscript received for publication 5 July 1983

Abstract

This program gives the log weight that the skidder can move and gives fuel consumption either in liters or gallons per turn. Slope of the skid trail, skidder weight, and skid distance must be entered into the program.

Introduction

Loggers work for profit and therefore seek improved efficiency to increase profits. Increasing costs constantly face logging operators. Efficiently loading a skidder will help reduce costs per unit of wood skidded, and we have developed a program for doing this. The Hewlett-Packard-41C[1] hand-held calculator program can be used as a tool to quickly compare loads and fuel used by wheeled skidders under different skidding conditions. Although a great number of variables influence skidding, only the major ones were used to simplify this hand-held calculator program and to give the operator items of input that can be readily determined. Iff and others (1982) incorporated 39 variables pertaining to skidder capacity in a Fortran program to obtain the skidder load. The program presented here will not compare to the highly sophisticated program. The trade-offs gained are simplicity of use and the low-priced, highly portable equipment that can be used almost anywhere.

The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program. For information, please write: Engineering Research, Northeastern Forest Experiment Station, 180 Canfield Street, Morgantown, WV 26505. If you want to obtain the program, send three blank Hewlett-Packard magnetic cards. Features of the HP-41C are presented in Appendix A. A program list is provided in Appendix B.

[1/] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Program Characteristics

The program gives not only a load that the skidder will pull but also the fuel per turn. Input items for load are skidder weight and slope for the loaded skidder. Distance of skid is added to calculate fuel used per turn. When slope and skidder weight are entered into the program, the maximum log weight for the load appears. Values of traction, rolling resistance, and sliding friction used in the program limit the maximum weight of the load. The selected values for these variables should give an accurate answer in the majority of situations; however, extra soft soil or overly rocky conditions could readily change the practical value of the maximum load.

Prompts

After starting the program, the first prompt "SLOPE?" appears. Percentage of slope for the average skidding distance should be entered as a whole number. Use positive slope for uphill skidding and negative slope for downhill skidding. If vast variations in slope exist over the skidding distance, various sections of the skidding distance could be treated independently and then combined. Press the R/S (run/start) key after entering slope and the next prompt "SKIDDER WT?" appears.

Skidder weight may be entered either in kilograms or in pounds. Readout for log weight of the load will be in the same units as entered for skidder weight. If 10 percent has been entered for slope and 12,000 kilograms or pounds entered for skidder weight, the calculator screen will show "LG WT = 5,610" in the same units used for skidder weight, giving the maximum log weight for the load after pressing the R/S key. Press the R/S key again and the prompt "LG WT?" appears. A value may be entered for load and the R/S key pressed or the R/S key may be pressed with no entry. With no entry, the maximum value of the load will be used for further calculations. By making no load entry and pressing the R/S key with the previous entries, the screen shows "FORCE = 10,071" in the same units used for skidder weight. This force value is the force exerted by the skidder to the soil to move the skidder and the load.

Pressing the R/S key produces "SKID DIST?" on the calculator screen. This asks for skidding distance for a section of skidroad with a relatively constant slope. If kilograms have been used for the skidder weight, the skid distance must be entered in meters. If pounds have been used for the skidder weight, the skid distance must be entered in feet.

Press the R/S key and the screen shows "METRIC?". If kilograms and meters have been used for entries, press number "1" to indicate yes. If pounds and feet have been used for entries, press "0" to indicate no. This permits either system of measure to be used with the same program. If a skid distance of 1,000 feet has been entered and "0" pressed for metric, pressing the R/S key will give an answer of "GAL = 0.355," which would be the gallons of fuel used for one round trip. If a skid distance of 1,000 meters has been entered and "1" pressed for metric, the R/S key produces "LITERS = 9.715," which would be the liters of fuel used for one round trip. The round trip and machine size are both much greater for kilograms and meters than they are for pounds and feet when the same numbers are used.

Input

Best values available should be used for input. Of course, compatible units must be used, either metric or English. The skidder weight given by the manufacturer generally would have greater accuracy than the other inputs. Because the program is for practical use, it does not require extreme precision.

Skidding distance changes with almost every load, thus an accurate estimate may be sufficient. If map measurements or ground measurements are available, an average of the maximum and minimum distance will give a reasonable value if the difference of maximum and minimum is not too great. Where slope changes control a section of skidding distance, a ground measurement would be most accurate. Slope would best be determined with an Abney level, or with a more modern device.

Readout

Some answers appear before making all inputs. This shows in the load which has a readout for maximum load followed by a prompt asking for the load value. Because maximum load generally cannot be obtained with normal operating conditions, this sequence is necessary and a reasonable load may be inserted. Also, the maximum load does not change for downhill or negative slopes.

Fuel consumption per turn includes bringing in the load and making the return trip. Fuel consumption should be considered comparative since this program is greatly simplified from one that considers all of the variables. When a logger works in conditions similar to one where this program has been used, the accuracy of fuel output could be verified, or if necessary, a correction factor could be applied. This situation would permit using fuel output as an absolute value. In any event, a comparison of costs can be made between full and partial loading.

Load

Loading a skidder probably affects efficiency more than any other variable in logging. This program along with production records will demonstrate to the user what additional costs occur from under loading skidders. Consistent loading to skidder capacity is impossible, unless logs are cut to the right size for specific conditions. Loads approaching the maximum can be achieved with experience.

Downhill slopes permit enormous loads to be pulled. However, moving a load considerably larger than the skidder creates a hazard. The program contains a loop for negative or downhill slopes that gives a load that can be pulled on level ground. This maximum load for negative slopes is realistic for two reasons: (1) this gives a safe-size load, and (2) most downhill skidding has at least one level location on the skid trail or landing and the load could not be efficiently changed for this location.

The criteria set up to determine the maximum load were: (1) sliding friction of 85 percent, (2) rolling resistance of 20 percent, and (3) tractive coefficient of 48 percent. Sliding friction of 85 percent is near that measured by Falk and Peters (1979) for west coast cable thinning. They reported 86 percent for an average. The value used also is in the lower range of tests run by Hassan and Gustafson (1981) in North Carolina.

The rolling resistance of 20 percent is suggested by Phillips (1981) for skidders on skidroads. Most of the skidding would be done along a skid trail. The tractive force of the skidder can range to near 85 percent (Iff and others 1982), but slippage would be excessive for any practical use. Nebraska tractor tests (Nebraska Board of Tractor Test Engineers 1980) for farm tractors stop when slippage reaches 20 percent. Burt and others (1982) indicate a range of 45 to 50 percent traction on a relatively firm skid road with 20 percent slip. Thus, 48 percent was selected for the program.

Conditions vary, and loads may be greater than those indicated as maximum. The calculated values should be realistic for most skidding conditions. Where the soil is very firm and traction excellent, tipping of the skidder would be the limiting factor on loading. Loads calculated by the program will not tip a skidder in any reasonable situation.

Formulas

The program was written from derived formulas using slope, rolling resistance, sliding friction, and internal friction of the skidder. The assumptions were made that one-half of the log weight was supported on the skidder, and that the skidder and load were moving on a uniform slope (Fig. 1). Internal friction of the skidder is used for fuel consumption. Twenty-five percent of the skidder weight was used for internal friction. This percentage agrees with a low range of both Matthes

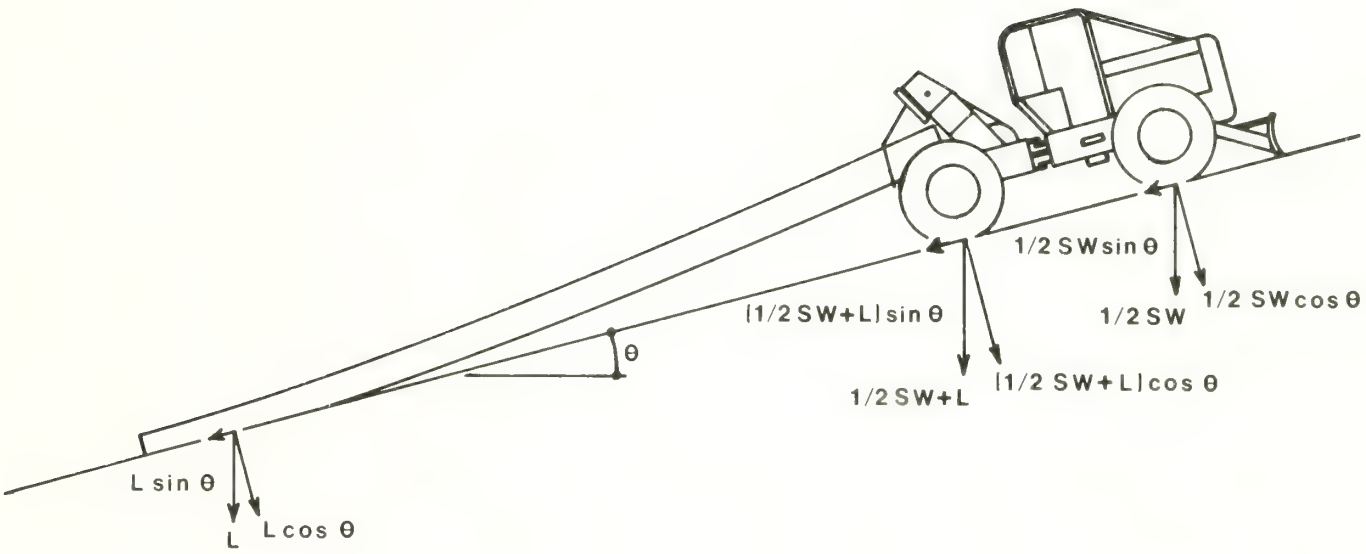

Figure 1.—Force diagram for loaded skidder.

and others (1982) for skidders and Chew (1980) for futuristic trucks.

Values

Slope	= θ
Rolling resistance	= 0.20
Internal friction	= 0.25
Tractive coefficient	= 0.48
Sliding friction	= 0.85
Skidder weight	= SW
One-half log weight	= L
Gravity component normal to slope	= cos θ
Gravity component along slope	= sin θ

Tractive force = resistive force

1. $0.48\ SW \cos\theta + 0.48\ L \cos\theta = 0.2\ SW \cos\theta + 0.2\ L \cos\theta + SW \sin\theta + 2\ L \sin\theta + 0.85\ L \cos\theta$

   transpose

2. $0.48\ L \cos\theta - 0.2\ L \cos\theta - 2\ L \sin\theta - 0.85\ L \cos\theta = 0.2\ SW \cos\theta + SW \sin\theta - 0.48\ SW \cos\theta$

   combine and change signs

3. $2\ L \sin\theta + 0.57\ L \cos\theta = 0.28\ SW \cos\theta - SW \sin\theta$

   solve for 2 L = log weight

4. $2L = SW \dfrac{0.28 \cos\theta - \sin\theta}{0.285 \cos\theta + \sin\theta}$

Return to the basic concept of the skidder pulling a log on a uniform slope. The force exerted along the slope is F.

5. $F = 0.85\ L \cos\theta + L \sin\theta + 0.2\ L \cos\theta + L \sin\theta + 0.2\ SW \cos\theta + SW \sin\theta$

   combine

6. $F = \dfrac{1.05}{2}(2L) \cos\theta + 0.2\ SW \cos\theta + (SW + 2L) \sin\theta$

Internal friction of 0.25 SW is added to the force for determining energy:

7. $F = \dfrac{1.05}{2}(2L) \cos\theta + 0.2\ SW \cos\theta + (SW + 2L) \sin\theta + 0.25\ SW$

Energy consumed bringing the load in is force times distance, and for the return trip, θ is changed to -θ and a load of 0 is used. Energy per turn is E.

8. $E = F \times D + (0.2\ SW \cos(-\theta) + SW \sin(-\theta) + 0.25\ SW)D$

E may be either in kilogram-meters or in foot-pounds. The conversion factor from kilogram-meters to kilowatt-hours is 1,980,000. The conversion factor from foot-pounds to horsepower-hours is 367,100.

Use 4 kilowatt-hours per liter of fuel oil (Chew 1980, Nebraska Board of Tractor Test Engineers 1980) for a round number near average to convert energy to quantity of fuel. This value converts to 20.3 horsepower-hours per gallon of fuel oil.

9. Fuel = E/1,980,000/4 liters per turn.

10. Fuel = E/367,100/20.3 gallons per turn.

These formulas incorporated into the flow chart (Fig. 2) result in the program listed in Appendix B.

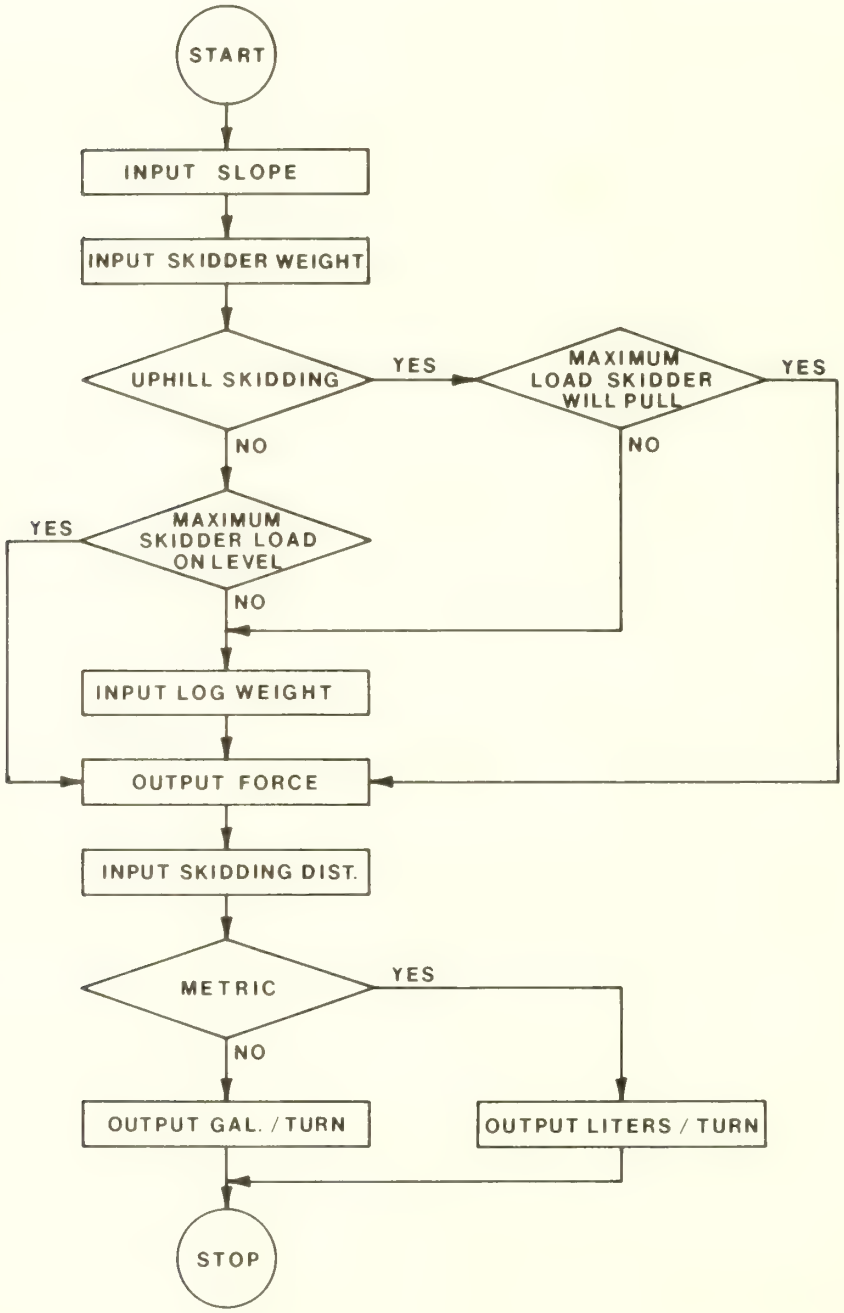

Figure 2.—Flow chart.

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Appendix A

Calculator Description

The hand-held Hewlett-Packard 41C contains programmable capabilities and a reasonably extensive storage. The calculator was designed for easy entrance of program storage. The program may be entered by direct programming, which is relatively simple, or through magnetic cards. Magnetic cards offer quick recovery of the program after some interruption such as using another program. The calculator's continuous memory holds the program as long as the storage space is not used for something else and even when the calculator is turned off. The reader will also transfer a program to magnetic cards.

Visual prompting for data shows on the visual display of the calculator so the program can readily be used at logging sites or any other place where a quick answer would be desirable.

The calculator signals for low batteries when BAT appears in the lower left side of the viewscreen. This signal indicates the need for a battery change. Old batteries may cause erratic functions of a program, even before the calculator indicates a need for battery change.

Appendix B

Skidder Load Capacity and Fuel Consumption HP-41C Program List

```
01 LBL "FUEL"
02 FIX Ø
03 "SLOPE?"
04 PROMPT
05 1ØØ
06 /
07 ATAN
08 STO Ø6
09 COS
10 STO Ø2
11 RCL Ø6
12 SIN
13 STO Ø1
14 "SKIDDER WT?"
15 PROMPT
16 STO Ø3
17 RCL Ø2
18 *
19 .28
20 *
21 RCL Ø3
22 RCL Ø1
23 *
24 -
25 RCL Ø1
26 RCL Ø2
27 .285
28 *
29 +
30 /
31 STO Ø4
32 RCL Ø3
33 .9825
34 *
35 RCL Ø4
36 X<>Y
37 X< =Y?
38 GTO Ø9
39 GTO 1Ø
40 LBL 1Ø
41 RCL Ø4
42 "LG WT ="
43 ARCL X
44 PROMPT
45 STO Ø5
46 "LG WT?"
47 PROMPT
48 STO Ø5
49 GTO Ø8
50 LBL Ø9
51 "LG WT ="
52 ARCL X
53 PROMPT
54 STO Ø5
55 "LG WT?"
56 PROMPT
57 STO Ø5
58 LBL Ø8
59 1.Ø5
60 2
61 /
62 *
63 RCL Ø2
64 *
65 RCL Ø3
66 .2
67 *
68 RCL Ø2
69 *
70 +
71 RCL Ø3
72 RCL Ø5
73 +
74 RCL Ø1
75 *
76 +
77 RCL Ø3
78 .25
79 *
80 +
81 "FORCE ="
82 ARCL X
83 PROMPT
84 STO Ø5
85 "SKID DIST.?"
86 PROMPT
87 STO Ø7
88 *
89 STO Ø9
90 RCL Ø6
91 CHS
92 STO Ø6
93 COS
94 RCL Ø3
95 *
96 .2
97 *
98 STO Ø8
99 RCL Ø6
100 SIN
101 RCL Ø3
102 *
103 RCL Ø3
104 .25
105 *
106 +
107 RCL Ø8
108 +
109 RCL Ø7
110 *
111 RCL Ø9
112 +
113 STO Ø1
114 FIX 3
115 "METRIC?"
116 PROMPT
117 X=Ø?
118 GTO Ø6
119 GTO Ø7
120 LBL Ø6
121 RCL Ø1
122 198ØØØØ
123 /
124 2Ø.3
125 /
126 "GAL ="
127 ARCL X
128 PROMPT
129 GTO Ø5
130 LBL Ø7
131 RCL Ø1
132 367100
133 /
134 4
135 /
136 "LITERS ="
137 ARCL X
138 PROMPT
139 GTO Ø5
140 LBL Ø5
141 "END"
142 PROMPT
143 "RTN"
144 STOP
145 END
```

Phillips, Ross A. **Skidder load capacity and fuel consumption HP-41C program.** Res. Pap. NE-537. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 7 p.

Program gives log weight that the skidder can move and gives fuel consumption either in liters or gallons per turn. Slope of the skid trail, skidder weight, and skid distance must be entered into the program.

ODC 389

Keywords: Skidder, load capacity, logging, computer programs, cost estimating, fuel estimating, skidding forces and distances.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1983-705-029:2

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United States
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Research
Paper NE-538

1984

An Analysis
of European Demand for Oak Lumber

William G. Luppold

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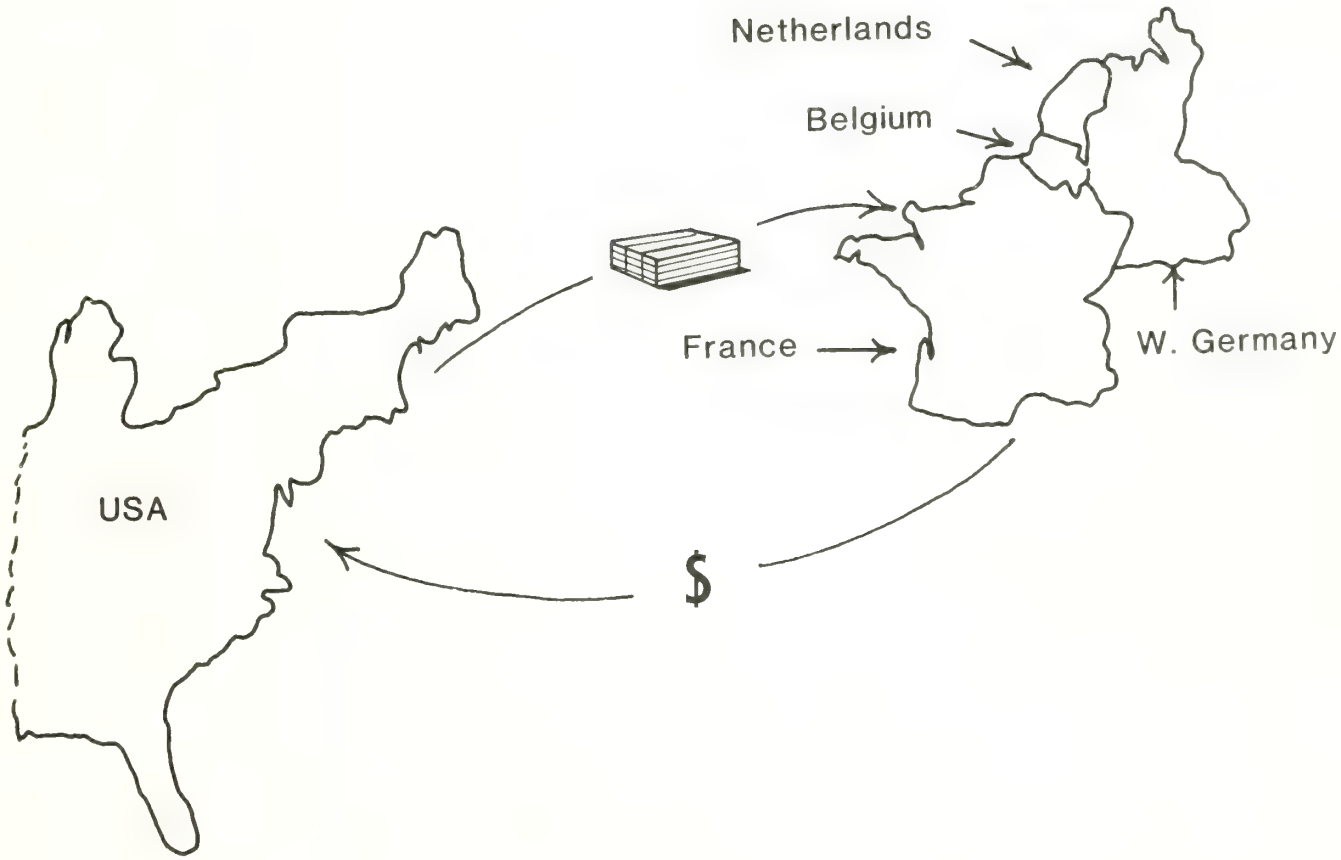

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Manuscript received for publication 26 May 1983

Abstract

Exports of oak lumber from the United States to the Netherlands, Belgium, Germany, and France were analyzed using ordinary least squares estimation procedures. The analyses indicated that the large increases in European demand for U.S. oak during the 1970's were caused by a combination of the dollar's depreciation against currencies of major European demanders, increases in prices of European oaks, increases in output prices in Europe, and furniture style changes.

Introduction

The surge in hardwood lumber exports during the last decade signaled an increasing foreign demand for lumber produced in the United States. In 1971, exports of hardwood lumber were only 110 million board feet, or 1.6 percent of domestic production. Of this, only 10 million were shipped to European countries. However, exports began to increase after 1971 so that by 1980 total exports reached 350 million board feet and exports to Europe increased to 157 million board feet. But by far the most significant aspect of the change in exports was that 102 million board feet, or nearly 30 percent of the total, were oak shipments to four countries—the Netherlands, Belgium, Germany, and France. Shipments to these countries increased by 1,600 to 3,000 percent in a period of just 8 years (Table 1).

The domestic effects of the dramatic increase of oak exports to Europe are somewhat mixed. European buyers have been willing to pay a premium for high-grade plain and quartered-cut oak lumber, causing the price of Firsts and Seconds (FAS) oak to increase tremendously. Many producers and wholesalers of hardwood lumber have benefited from the premium prices being paid for high-grade oak and have changed their marketing practices to accommodate European buyers. But many domestic demanders are complaining about the increases in lumber price, while other domestic demanders claim that the large profits being made by suppliers of the higher grades make domestic supplies of No. 1 and No. 2 Common lumber available at a lower price.

In order to understand why European demand for domestically produced oak has increased so dramatically and judge whether it will continue to increase in the future, the demands for oak lumber by major importing countries must be quantified. Then the factors that have caused the change can be isolated and measured. Such information can be used by domestic demanders and suppliers to anticipate changes in European demands in the future, and thus to make better production and usage decisions. Forest resource planners and other government officials also can use the information to develop export marketing programs.

Literature pertaining to international trade in forest-related commodities is available, but literature pertaining to international demands for hardwood lumber is scarce. Although Chou and Buongiorno (1984) have estimated demands for hardwood lumber by European countries and Camous (1980) has studied the effects of exports on French oak price, no study has addressed export demand for hardwood lumber of a specific species to a specific country.

Table 1.—Volumes of oak lumber exported to major European demanders and percentage changes in exports for the years 1973 through 1980, in thousand board feet (Mbf)

Country	1973	1976	1977	1978	1979	1980	Percentage change 1973–1980
Norway	2,168	1,748	2,031	1,210	1,747	2,009	– 7.3
Denmark	776	863	888	1,087	678	1,561	101.2
United Kingdom	3,744	327	680	957	1,447	2,848	– 23.9
Ireland	323	315	301	586	313	415	28.5
The Netherlands	904	7,714	12,366	27,297	23,471	26,829	2,867.8
Belgium	1,788	6,388	5,079	11,850	20,467	30,373	1,598.7
Germany	1,196	3,461	9,238	19,712	24,586	37,018	2,995.2
France	525	334	986	2,639	5,105	10,504	1,900.8
Spain	2,284	2,794	2,140	2,823	5,196	3,373	47.4
Italy	908	417	389	894	3,361	9,660	963.9

SOURCE: U.S. Department of Commerce, Bureau of the Census, *U.S. Exports Schedule B. Commodity by Country.* Report 410, Washington, DC.

Model Development and Data Base

Economic theory stipulates that the demand for a productive input is a function of the price of the input, prices of other inputs, and price of the output. Export demand relationships developed by Leamer and Stern (1970) and others follow the general form stipulated by theory except for the substitution of industrial production or economic activity level for the price of output. Since information on levels of economic activity is more easily found than output price information, the substitution of economic activity level for price of output is probably made for convenience. The current study attempts to formulate the demand relationships in the form that is stipulated by economic theory, within the bounds of data availability.

The data base used for equation estimation consists of observations made quarterly from 1973 through 1979. This period was chosen because it is representative of the current international monetary market structure, which underwent a structural change in 1973. Information on the quantities exported was obtained from *U.S. Exports Schedule B. Commodity by Country* (Report FT410), compiled by the U.S. Department of Commerce, Bureau of the Census.

The price of the input in the demand relationships for the various countries was the price of American FAS red oak lumber plus whole carlot premium as reported in the *Hardwood Market Report* (Lemsky 1970, 1980). *Hardwood Market Report* prices were used instead of unit prices derived from export statistics because unit prices are affected by merchandising costs such as sorting, drying, and stacking. These have changed over time as American exporters have learned more about their customers, making unit prices an inconsistent measure of the price being paid for the actual lumber. The price of FAS lumber was used because Europeans tend to purchase high-grade "clear" lumber. The premiums were added to the FAS price because shipments of lumber bound for export are usually composed mostly of high-grade lumber. Red oak price was used rather than a combination of red and white oak prices because the reported prices of these species were nearly the same between 1973 and 1979.

The price of French oak was included in the demand relationship to represent the price of substitute species. Although French and U.S. oaks are not perfect substitutes for one another, many European furniture and cabinetmakers can use either species after a short adjustment period. The French oak price series used was released by the French office, National des Forets, Department Commerical, in a publication by Christian Camous entitled "La Formation du Prix du Chene en France, Une Etude Econometrique" (1980).

An important consideration in the price of an imported input is the exchange rate between countries. The exchange rate can be considered a separate variable in model specification, or it can be used to adjust price from one currency to another. Theoretically, it is more sound to adjust price with exchange rate because the adjusted price is the one that foreign demanders face in the marketplace. Since countries like Belgium import oak from both France and the United States, the prices of these commodities must be based on the currency of the importing country. Exchange rates and indexes were obtained from the *Monthly Bulletin of Statistics*, published by the United Nations.

The selection of an output price variable was complicated by the facts that furniture prices in the individual countries were unobtainable and reported price indexes for general commodity groups were inconsistent across countries. Given these difficulties, the most appropriate available price indexes were selected for each country. The indexes for finished goods were used in the German and Dutch demand relationships, while the indexes for domestic goods prices were used in the Belgian and French equations. All indexes were obtained from the *Monthly Bulletin of Statistics*.

Since past levels of lumber price, interest and wage rates, and output prices were found to affect aggregate demand for hardwood lumber in the United States, (Luppold 1982), past levels of U.S. oak price, French oak price, and output price may affect current export demand. If the European demanders react like their American counterparts, a lag specification of 1 to 3 years and polynomial in form should be tested. The polynomial, or "inverse U", lag structure indicates a situation where a change in price exerts an increasing, then decreasing influence on demand over time.

One additional variable that has influenced the quantity of oak lumber exported to Europe is the change in furniture styles throughout the continent. Prior to 1975, oak lumber was used in traditional furniture, while mahogany and teak were used in fashionable furniture; but in the mid 1970's, a quick change to oak in the fashionable furniture market occurred, creating a larger demand for oak (Ascherman 1983). To account for this change, a dummy variable was included in the model with the dummy equaling 1 for dates after 1975 and zero otherwise.

Model Estimation

The estimated demand equations for the Netherlands, Belgium, Germany, and France are presented in Table 2. All the equations fitted the data well, as indicated by the "t" statistics and the R^2's. All non-intercept variables were of the expected sign and were significant at the 0.05 level or better. The Durbin-Watson (D-W) statistic for the Belgian equation indicated no autocorrelation, while the D-W values of the other equations fell in the inconclusive range.

The length and appropriate type of lag structure used in the individual price variables in each equation were empirically determined. The demand equations for the Netherlands, Belgium, and Germany had identical specifications of polynomial lagged price variables. The French equation was composed of moving averages that were 3 quarters in length.

Table 2.—Statistically estimated U.S. oak export demand relationships for the Netherlands, Belgium, Germany, and France

Country	Variable	Coefficient	t statistic	Nature of lag
The Netherlands	Intercept	9597.6	1.56	—
	U.S. oak price	− 2.165[a]	2.91**	Polynomial t-2 through t-6
	French oak price	.687	− 2.29*	Polynomial t-1 through t-4
	Price finished goods	4.286	− 2.44*	Polynomial t-1 through t-4
	1976 dummy	2670.3	3.50**	—
			R^2 = .833	
			D-W = 1.18	
Belgium	Intercept	10957.1	4.34**	—
	U.S. oak price	− 2.864	7.31**	Polynomial t-2 through t-6
	French oak price	1.369	− 8.32**	Polynomial t-1 through t-4
	Price domestic goods	5.585	− 4.43**	Polynomial t-1 through t-4
	1976 dummy	780.9	1.79*	—
			R^2 = .877	
			D-W = 1.81	
Germany	Intercept	9420.6	2.29*	—
	U.S. oak price	− 2.489	5.71**	Polynomial t-2 through t-6
	French oak price	.753	− 3.48**	Polynomial t-1 through t-4
	Price finished goods	5.072	− 3.47**	Polynomial t-1 through t-4
	1976 dummy	2754.4	5.33**	—
			R^2 = .922	
			D-W = 1.49	
France	Intercept	931.5	1.21	—
	U.S. oak price	− 13.58	− 4.83**	Moving average t-1, t-2, t-3[b]
	French oak price	.696	2.97**	Moving average t-1, t-2, t-3
	Price domestic goods	18.27	3.79**	Moving average t-1, t-2, t-3
	1976 dummy	658.0	4.00**	—
			R^2 = .864	
			D-W = 1.47	

[a] The coefficients associated with the polynomial lags are the opposite signs of the resulting elasticities because negative weights were used in their calculation (See Maddala 1977).

[b] Moving averages representing an even lag distribution performed better than polynomial lag structures in the French equation.

** Significant at $\alpha = 0.01$.

*Significant at $\alpha = 0.05$.

Analyses

Demand elasticities for U.S. oak price, French oak price, and output price for the Netherlands, Belgium, Germany, and France are shown in Table 3. The elasticities are cumulative, or long-term, elasticities which reflect the total impact of a change in an explanatory variable after a period of up to 18 months. The elasticities presented are at 1980 prices and quantities to be most reflective of current market activity.

As should be expected, the long-term price elasticities of U.S. oak are relatively high, ranging from 3.8 for the Netherlands to 5.4 for Belgium. Such high long-term price elasticities are not unusual for a high-value, limited-use imported item. The high elasticities indicate that a change in oak price in the United States or a change in exchange rates has a rather large impact on the demand for U.S. oak. This change did not begin instantly, rather the effect was spread over 2 to 6 quarters in the Netherlands, Belgium, and Germany, and 1 to 3 quarters in France.

The dummy variable which was included to account for the style change in European furniture was statistically significant in all the demand equations. The level of the change in millions of board feet can be determined directly from the coefficient associated with the dummy variable. The style change affected German and Belgian demand to a much greater degree than it affected the demands of France and the Netherlands.

The elasticities in Table 3 show the relative influence of a 1-percent change in the various prices on quantities exported. However, in order to analyze why the quantities exported changed so dramatically during the 1970's, the percentage changes in U.S. and French oak prices (adjusted for exchange rates) and changes in output prices must be considered. These changes are shown in Table 4.

Although the price of U.S. oak increased by more than 100 percent in U.S. dollars between 1973 and 1979, the price of U.S. oak in the Netherlands, Belgium, and Germany rose only 11 to 32 percent because of the large depreciation of the U.S. dollar against European currencies during the 1970's (Table 5). The price of U.S. oak in France increased by 65 percent because the U.S. dollar did a little better against the French franc than against the Dutch guilder, the Belgian franc, or the German mark. Of course, any price increase would discourage demand for U.S. oak; but a small price increase in U.S. oak would be more easily offset by an increase in French oak price or output price.

French oak price increased by 414 percent between 1973 and 1979 (Table 4), but the increases in French oak price in the Netherlands, Belgium, and Germany were considerably less because of the weakness of the French franc. Still, price increases of 248 percent in Germany, 297 percent in Belgium, and 283 percent in the Netherlands more than offset the increase of U.S. oak price, even considering the differences in price elasticities. Ironically, the large increase in French oak price has been attributed to exports of French oak (Camous 1980). According to this theory, an increased demand for French oak caused the price of French oak to rise, which, in turn, caused the demand for and price of U.S. oak to increase. The initial increase in French oak demand was probably caused by the decreased availability of Japanese oak and the decreasing availability of tropical species from Africa and Asia.

Table 3.—Cumulative elasticities of demand for U.S. oak in the Netherlands, Belgium, Germany, and France with respect to price of U.S. oak, price of French oak, and price of output at 1980 levels

Country	Price of U.S. oak	Price of French oak	Price of output
The Netherlands	– 3.80	0.99	2.43
Belgium	– 5.41	2.13	2.98
Germany	– 4.05	1.00	2.62
France	– 4.66	1.73	3.35

Table 4.—Percentage changes in U.S. oak price, French oak price, and output price for the Netherlands, Belgium, Germany, and France, 1973-1979

Country	Price of U.S. oak[a]	Price of French oak[b]	Price of output
The Netherlands	23	283	57
Belgium	32	297	45
Germany	11	248	52
France	65	413	118

[a] Adjusted for exchange rates between the U.S. and the demanding country.
[b] Adjusted for exchange rates between France and the demanding country.

Table 5.—Percentage changes in the U.S. dollar and the French franc against the currencies of the Netherlands, Belgium, Germany, and France, 1973-1979

Against the. . .	Change in the value of the U.S. dollar	Change in the value of the French franc
Dutch guilder	– 39	– 25
Belgian franc	– 35	– 21
German mark	– 44	– 34
French franc	– 18	—

Luppold, William G. **An analysis of European demand for oak lumber.** Res. Pap. NE-538. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1984. 7 p.

Exports of oak lumber produced in the United States to major European demanders were analyzed using ordinary least squares estimation procedures.

ODC 722.4

Keywords: Economics; exports; hardwoods

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984-705-029:26

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United States
Department of
Agriculture

Forest Service

**Northeastern Forest
Experiment Station**

Research Paper
NE-539

1984

Effect of Thinning
on Growth and Potential Quality of Young White Oak Crop Trees

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Manuscript received for
publication 10 June 1983

Abstract

Relative change in several types of stem defects were studied over a 16-year period to determine the effect of thinning intensity on the development of tree quality. We studied quality changes on sample white oak crop trees that were selected from five density levels created in a 1961 thinning. Branch-related and other stem defects on the butt 16-foot section were studied from stereo pairs of photographs taken in 1961 and 1977. The number of live and dead branches greater than 0.3 inch in basal diameter increased on all density plots. Except for extremely heavy thinnings, those below C-level stocking, tree quality was not markedly affected by residual stand density.

Introduction

The goal of hardwood managers often is to produce high-quality trees for lumber or veneer in the shortest possible time. A primary means of achieving this is regulating residual stand density through a series of intermediate cuttings. These treatments affect the growth rate of individual trees as well as the development of bole quality. Gingrich (1970) suggested that thinnings in hardwoods should depend more on species composition, tree vigor, and potential stem quality than merely on growth response due to reduced stand density. The effects of residual stand density on growth rates are better understood and documented than its effects on the development of stem quality. This report summarizes research findings on the development of limb-related defects and other quality characteristics associated with a range of residual stocking levels created by an earlier thinning.

Cull, defective, and lower quality stems are removed during intermediate cutting; and this process of eliminating undesirable trees theoretically enhances the development of high-quality stems. However, detrimental effects on stem quality can result, especially from extremely heavy cutting. The rate of natural pruning of live limbs also can be reduced and, in some instances, heavy cutting promotes increased branching and degrade through epicormic sprouting. Generally, changes in tree quality occur very slowly, so it is difficult to detect and quantify this rate of change on an objective basis. And little response data are available from long-term studies of changes in tree quality.

Research on bole-quality development following thinning has been neglected but not ignored completely. Stem-quality development in hardwoods is recognized to be at least as important as growth in defining optimum stocking regimes (Tubbs 1977). Since branch-related defects are the most common cause of degrade in hardwoods (Bryan 1958; Godman and Books 1971), the effect of stand stocking on branch occurrence, development, and retention is especially important. In the oak type, Brinkman (1955) reported that the tendency for individual trees to develop epicormic branches might be inherited, though the amount of branching was influenced by degree of partial cutting and the relative crown class. More epicormic branches were found in understocked stands and on trees in the subdominant crown position. Krajieck (1959) reported similar results for a 95-year-old stand of white oak where dominant stems had fewer than 3 epicormic branches on the lower 17 feet, while stems in other crown classes had 6 to 10 branches. Oaks are more prone to develop epicormic branches than species such as yellow-poplar or white ash (Smith 1966). White oak apparently produces and retains more branches or epicormics than most other species, even other oaks (Della-Bianca 1983). Research has shown that in hardwood forests the occurrence and persistence of branches—both living and dead—varies with species, tree age, crown class, site quality, and stand density.

This study examined changes in various types of limb-related defects and other tree-quality factors for white oak crop trees over a 16-year period. We were especially interested in the relative rate of change in defect indicators over the extremely broad range in stand densities created by an initial thinning in 1961. The rate of change and the trends in potential tree defects coupled with information on growth and cost of treatment will help evaluate tree and stand values and serve as a basis for selecting silvicultural treatment regimes.

Methods

Data on tree quality were collected on sample crop trees from a thinning on the Daniel Boone National Forest, Jackson County, Kentucky. The design consisted of fifteen 1/2-acre plots, plus an isolation zone of about 1/2 acre surrounding each plot. At the time of the initial thinning in 1961, this fully stocked natural white oak stand was 33 years old and showed no evidence of fire, cutting, or other disturbance. All plots were remarkably uniform in basal area, age, distribution of size class, species composition, and site quality. Before thinning, the plots averaged 687 trees per acre that were 2.6 inches or larger in d.b.h. and 75 ft^2 of basal area.

The average mean stand diameter was 4.5 inches and the average site index was 70. White oak was the principal species accounting for more than two-thirds of all trees over 2.6 inches in d.b.h. Other oaks, mainly black and scarlet, accounted for 19 percent of the trees, while hickory, black gum, and red maple accounted for most of the remaining 14 percent.

Three plots each were thinned to residual basal areas of 15, 30, 45, and 60 ft^2 per acre, leaving the three control plots with approximately 75 ft^2 per acre. The objective was to leave a suitable number of the best stems as evenly spaced as possible over the plot. In general, we cut the larger cull and defective trees first, then the competing trees of poor form and quality, then the intermediate and suppressed trees of lower quality and value. Finally, if necessary, we cut the lower value species of the main crown class. High-quality desirable species were cut also if necessary to achieve a uniform spatial distribution. Table 1 shows that much of the thinning was from below.

Dominant and codominant white oak trees that were well dispersed over the plot were selected as sample trees.

Table 1.—Relative frequency of trees larger than 2.6 inches in dbh after 1961 thinning, by crown class

Crown class	Residual basal area after 1961 thinning (ft²/acre)									
	15		30		45		60		75	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Dominant	22(5.4)[a]	18	30(5.9)	12	33(6.4)	8	54(6.1)	8	46(6.7)	7
Codominant	64(4.9)	53	127(4.9)	49	181(5.0)	45	217(4.7)	34	233(4.7)	33
Intermediate	34(3.9)	28	88(4.0)	34	119(3.8)	29	198(3.7)	31	176(3.6)	25
Suppressed	1(3.8)	1	13(3.4)	5	72(3.1)	18	168(3.0)	27	247(3.2)	35

[a]Quadratic mean diameter in parenthesis.

They were selected because of their high potential as crop trees based on tree vigor, crown position, dbh, and the apparent quality judged by form, straightness, freedom from branches, and other defect indicators. Five of these sample trees were selected randomly to determine changes in tree quality by the stereo-photo technique described by Worley and Dale (1960). This technique entailed taking stereo pairs of photographs from the four cardinal directions in 1961 and again in 1977 after 16 growing seasons. Because of the poor quality of some of the 1961 photographs, the sample consisted of only 66 trees.

Various types of stem characteristics and limb-related defects were identified and classified on each sample tree from 1961 and 1977 photographs. Prints of each negative were enlarged to 8 × 10 inches and examined with 4-power stereoscopic binoculars. Other tree characteristics such as dbh, crown class, crown length, and total tree height were observed or measured in the field on both occasions. In 1961, total height and crown length were measured with a Haga altimeter.[1] Targets and a range finder were used to establish a horizontal distance 1 chain from the measured tree. In 1977, these measurements were taken with a relaskop at a taped distance of 75 feet from the tree. Crown length was measured starting with the first major branch in the main crown.

To verify the reliability of classifying branch defects from the photographs, we conducted an independent field test using the 1977 data. The number of branches, alive or dead, and branch size were classified independently in the field in 1977 and compared with data as observed and classified from the 1977 photographs. We were able to identify the total number of branches on the 16-foot butt section very well, obtaining a correlation between photo and ground observations of 0.98. This technique was not as accurate in determining whether the branches were alive or dead, but we were able to correctly classify the status, obtaining a correlation of 0.8.

Results and Discussion

As was expected, it was easier to document the effects of thinning on growth than on quality characteristics. The main focus of this paper is on quality, but growth is discussed briefly because of its importance in evaluating thinning practices.

Diameter Growth

The effect of stocking on growth was quite evident over the 16-year period for tree characteristics such as dbh and cubic volume (Table 2). Mean diameter growth of sample trees on the lowest density plots was twice as great as on the control plots. Differences in mean diameter growth due to thinning treatments were highly significant ($P < 0.01$). From the lowest to highest stocking, annual diameter growth was respectively: 0.28, 0.23, 0.18, 0.16, and 0.14 inch, or an increase over control of 100, 64, 28, and 14 percent. Hilt (1979) reported similar growth trends in relation to stocking based on a much larger base.

Height Growth

The effect of stocking on height growth appeared to follow a different pattern than for diameter or cubic-volume growth (Table 2). Mean height growth from lowest to highest stocking was, respectively: 15.4, 17.3, 17.4, 16.6, and 13.3 feet. Covariance analysis, adjusting for initial tree height, indicated no significant difference in mean height growth due to treatment.

Cubic-Volume Growth

Stocking level influenced cubic-volume growth even more than diameter growth but followed the same pattern (Table 2). Cubic-volume growth

[1] The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Table 2.—Summary of average sample tree characteristics in 1961 and 1977 for each thinning treatment

Characteristic	Year	Residual basal area after 1961 thinning (ft²/acre)				
		15	30	45	60	75
Dbh (inches)	1961	5.7	5.7	6.1	5.3	5.5
	1977	10.2	9.4	8.9	7.8	7.7
Crown class (% of trees)						
Dominant	1961	30.8	23.1	69.2	23.1	21.4
Codominant	1961	69.2	76.9	30.8	76.9	78.6
Dominant	1977	46.2	38.5	38.4	23.1	7.1
Codominant	1977	53.8	61.5	53.9	69.2	71.4
Intermediate-suppressed	1977			7.7	7.7	21.5
Crown ratio (% live crown)	1961	42.4	43.2	41.5	44.2	40.8
	1977	50.4	33.1	27.7	26.2	25.0
Total height (ft)	1961	51.8	52.2	53.5	51.2	51.3
	1977	67.2	69.5	70.9	67.8	64.6
Sweep and crook (departure in inches, 16-foot butt log)	1961	1.23	0.85	1.31	0.92	1.57
	1977	0.91	1.77	1.23	1.15	1.50
Cubic volume (ft³)	1961	4.8	4.8	5.6	4.2	4.5
	1977	18.0	15.9	14.6	10.9	10.1
Stem surface area on butt 16-foot (ft²)	1961	4.8	4.8	5.6	4.2	4.5
	1977	36.4	33.6	31.9	27.9	27.6

was 2 1/3 times greater per tree at the lowest stocking compared with the control. This was expected since diameter in the volume equation is squared while height enters as a linear term. From lowest to highest stocking, growth in volume for 16 years was, respectively: 13.2, 11.1, 9.0, 6.7, and 5.7 cubic feet per tree, or an increase over the control of 132, 95, 58, and 18 percent. Differences in mean cubic-volume growth between density levels after adjusting for initial volume were highly significant ($P < 0.01$). Although growth per tree is greatest at the lowest stocking, there are too few trees (121 per acre, Table 1) to fully occupy the site; hence, on a per-acre basis, growth is less at the lowest stocking level (Dale 1972).

Tree Crown

Stand density influenced both the crown position and crown ratio of sample trees. As was expected, the proportion of trees in the dominant crown class increased with lower stocking. Likewise, crown ratio increased. The crown class and crown ratios shown in Table 2 for 1961 were observed before thinning. In 1977, more of the sample trees at the lower stocking levels had a dominant crown position and greater crown length. These characteristics probably are responsible for the increased diameter and cubic-volume growth.

In 1961 there was little difference in crown length between density levels; the average was about 22 feet overall. By 1977, the average crown length was about 34 feet at the lowest stocking but had decreased to about 16 feet on the control plots. After adjusting for initial crown length, the difference in crown length in 1977 between treatments was highly significant ($P < 0.01$).

Statistical tests on total height, crown length, and diameter growth were recomputed, omitting trees that were intermediate or suppressed in 1977. Earlier results were not changed appreciably, though the mean diameter and mean total height increased slightly over the values given in Table 2 for density levels 60 and 75.

Quality Characteristics

Tree quality is not one single measureable characteristic but consists of many factors, some of which may depend on the intended product. Certain tree characteristics or factors, however, are generally regarded as desirable for most products. Such quality indicators might be stem straightness, freedom from branches and overgrown knots, absence of forks and crooks, few insect holes or wounds, no seams, and no evidence of internal or external decay.

In this study we identified and classified several types of defects or quality indicators such as crook and sweep; various classes of live and dead branches; forks; and overgrowths. Since limb-related defects are the greatest deterrent to potential tree quality (Godman and Books 1971; Bryan 1958), most of the analysis deals with various types and sizes of branches. It is difficult to interpret the effect of stocking on branch development unless all branch-related defects are considered simultaneously. For example, over the 16-year period it is possible for some small epicormic branches to develop into large, live limbs, later die, and finally drop from the stem and become overgrowths. Specific defects must be identified and their development traced over time to develop this information. We are doing this in a separate study. In this analysis we classified the various types of defects from the 1961 and 1977 photographs independently.

Branch Characteristics

The several categories of branches we recognized depended on size and whether the twig was alive or dead. Twigs that were alive and smaller than 0.3 inch in diameter at the base were classified as epicormic. Limbs 0.3 inch or larger in diameter were called branches and further classified as alive or dead (Table 3). The number of branches on the butt 16-foot section was recorded on each of the 8-foot stem sections. When the entire 16-foot log was considered (Table 3), it is obvious that the number of trees with live branches increased at all density levels between 1961 and 1977. The greatest increase in the number of live branches was at the lowest stocking level; here, the number of trees with branches increased from about 8 percent in 1961 to 92 percent in 1977. Although there were significantly more trees with branches in 1977 than in 1961, the increase did not appear entirely related to stocking level. Many twigs were less than 0.3 inch in diameter in 1961, but in 1977, they had grown larger and were classified as branches. We believe that most branches developed from the numerous epicormics present on most trees before the initial thinning in 1961 (Fig. 1).

Not only did more trees have branches in 1977, regardless of the density level, but there were more branches per tree. Table 3 shows that about 46 percent of the sample trees on the lowest density plots had at least five or more branches per tree. The following shows the average number of live and dead branches per tree for the 16-foot section at each density level:

Branch	*Residual basal area in 1961*				
	15	30	45	60	75
Live	5.0	2.46	1.92		1.79
Dead	3.62	1.15	0.85	<0.85	<0.50

Except for the control plots, the number of live branches decreased as stand density increased.

Covariance analysis that adjusts for the initial number of live branches in 1961 indicated that the effect of density on number of live branches was significant ($P < 0.08$). Comparison of density levels revealed significantly more live branches only at the lowest density level.

The effect of density on the number of dead branches was more evident. In 1961 there was no difference between density levels in the number of trees with dead branches on the butt 16-foot log (Table 3). The lowest density level had the most trees with dead branches, 40 percent in 1961, and all of the trees in 1977. Only the highest stocked plots showed a decrease in number of trees with dead branches between 1961 and 1977. The difference between density levels in the number of dead branches in 1977 was highly significant ($P < 0.01$). The lowest density had the most dead branches in 1977 but the lower two stocking levels were significantly different than the higher stocked plots ($P < 0.01$). The tabulation also shows that there were still more living than dead branches at all density levels in 1977.

There were significantly more living and dead branches in the upper 8-foot section of the butt 16-foot log. A comparison of the living branches for the lower and upper sections is shown in Table 4. Analyses indicated that the effect of stand density on both living and dead branches was the same for the upper section as for the 16-foot log. No analyses were performed on the lower stem section because less than 23 percent of sample trees had either living or dead branches on the lower 8 feet.

Table 3.—Percentage of sample trees in 1961 and 1977 by number of living and dead branches (butt 16-foot log)

Number of branches	Residual basal area in 1961 (ft²/acre)									
	15		30		45		60		75	
	1961	1977	1961	1977	1961	1977	1961	1977	1961	1977
					LIVING					
0	92.3	7.6	76.9	30.7	92.3	30.7	100.0	46.1	85.7	35.7
1-2	7.7	23.1	15.4	23.1	7.7	30.8	—	53.9	14.3	28.5
3-4	—	23.1	7.7	23.1	—	30.8	—	—	—	21.5
5-8	—	38.7	—	23.1	—	7.7	—	—	—	14.3
9-16	—	7.5	—	—	—	—	—	—	—	—
					DEAD					
0	61.5	—	100.0	46.1	69.2	61.5	69.2	61.5	64.2	85.7
1-2	38.5	15.3	—	46.2	30.8	23.1	30.8	38.5	28.6	14.3
3-4	—	61.6	—	7.7	—	15.4	—	—	7.2	—
5-8	—	23.1	—	—	—	—	—	—	—	—

Figure 1.—Typical 50-year-old white oak trees in fully stocked stands have many epicormics.

Table 4.—Percentage of sample trees in 1961 and 1977 by number of living branches in butt and second sections of 16-foot log

Number of branches	Residual basal area in 1961 (ft²/acre)									
	15		30		45		60		75	
	1961	1977	1961	1977	1961	1977	1961	1977	1961	1977
	BUTT SECTION									
0	100.0	84.6	92.3	76.9	100.0	84.6	100.0	100.0	100.0	78.5
1-2	—	15.4	7.7	23.1	—	15.4	—	—	—	22.5
	SECOND SECTION									
0	92.3	7.6	76.9	30.7	92.3	30.7	100.0	46.1	85.7	35.7
1-2	7.7	23.1	23.1	38.5	7.7	30.8	—	53.9	14.3	35.7
3-4	—	23.1	—	7.7	—	31.8	—	—	—	23.8
5-8	—	38.5	—	23.1	—	7.2	—	—	—	—
9-16	—	7.7	—	—	—	—	—	—	—	—

Epicormic Branches

Small epicormic branches were difficult to identify and count accurately from the photos so we only recognized three broad categories of trees with epicormic branches: none, one to six, or seven or more epicormics for each 8-foot section (Table 5). In both sections there were few trees with no epicormics in 1961. The percentage of trees free of epicormics on the butt 8-foot section in 1977 ranged from 23 percent at 15 ft^2 of basal area to 53 percent at 30 ft^2 of basal area (Table 5). The number of trees with no epicormics increased between 1961 and 1977 except at the lowest stocking level.

Branch Size

Average diameter of the largest living and dead branch on each 8-foot section is given in Table 6. Live branch size on the second 8-foot section was significantly ($P < 0.01$) related to stocking level. Branch size also appeared to decrease with increasing stocking on the lower sections, but no analyses were attempted because too few trees had branches. Live branches were slightly larger on the second 8-foot section, ranging from 1.0 inch at the lowest stocking to only 0.58 inch at the highest stocking. There was no correlation between stocking and size of dead branches after 10 years. In the future, dead branch size likely will be larger on the lower stocking levels since the live branches present today are now larger on the low-density plots.

We believe that the development of an extremely dense understory on the lower stocked plots (Fig. 2) may help explain some of the changes in branch size and number of dead branches. Initially, the lower bole of sample trees

Table 5.—Percentage of sample trees in 1961 and 1977 by the number of epicormic branches in butt and second section of 16-foot log

Number of epicormics	Residual basal area in 1961 (ft^2/acre)									
	15		30		45		60		75	
	1961	1977	1961	1977	1961	1977	1961	1977	1961	1977
					BUTT SECTION					
0	30.7	23.0	15.3	53.8	15.3	38.4	—	38.4	—	35.7
1-6	46.2	46.2	69.3	38.5	69.3	53.9	76.9	46.2	71.4	35.7
7+	23.1	30.8	15.4	7.7	15.3	7.7	23.1	15.4	28.6	28.6
					SECOND SECTION					
0	7.6	7.6	7.6	7.6	—	7.6	—	—	—	—
1-6	38.5	69.3	20.8	53.9	46.1	53.9	23.0	53.8	14.2	57.1
7+	53.9	23.1	71.6	38.5	53.9	38.5	77.0	46.2	85.8	42.9

Table 6.—Average size (basal diameter) of largest live and dead branch on each tree in 1961 and 1977

Item	Year	Residual basal area after thinning (ft^2/acre)				
		15	30	45	60	75
		Inches				
Live limbs Butt 8-foot section	1961	—	—	—	—	—
	1977	0.75	0.58	0.63	—	0.50
Live limbs Second 8-foot section	1961	0.50	0.50	0.50	—	0.50
	1977	1.00	0.80	0.67	0.60	0.58
Dead limbs Butt 8-foot section	1961	—	—	—	—	—
	1977	0.62	0.75	1.00	0.62	0.75
Dead limbs Second 8-foot section	1961	1.04	—	0.94	1.19	0.80
	1977	0.91	0.53	0.70	0.91	0.75

Figure 2.—Typical dense understory on a lower stocking plot in 1977.

was exposed to a great deal of direct sunlight, so epicormics developed and grew rapidly to branch size classification. A few years later, a dense understory was shading the lower 8-foot section, causing branch mortality or restricting growth. After 16 years, the understory is 25 to 30 feet tall and is shading the entire lower 16 feet. Even if branches die as quickly now on the lower as on the higher stocked plots, branches are larger and may require a longer period to drop off and become overgrown by clear wood. Also, the trees already are larger in diameter so even if branches do die shortly, the knotty core will be larger at the lower stocking levels.

Defects Per Square Foot of Surface Area

The number of defects per square foot of stem surface area provides a relative comparison of the effect of stocking on stem quality. Table 7 shows the number of live or dead branch defects per square foot of surface area. The number of such defects per square foot increased on all density levels over the 16-year period, but the greatest increase was on the lowest density plots. The ratio of 1977 to 1961 defects per square foot for the 16-foot log indicates nearly 8 times more defects per square foot in 1977 at the lowest stocking and nearly twice as many at the highest stocking. This ratio decreased as stocking increased from 7.9, 6.2, 4.1, 2.3 and 1.8. Live or dead branches on the second 8-foot section were responsible for most of the increase.

Table 7.—Number of live and dead limb defects per square foot of stem surface area

Item	Year	Residual basal area after 1961 thinning (ft^2/acre)				
		15	30	45	60	75
Butt	1961	—	0.005	—	—	—
8-foot log	1977	0.056	0.025	0.022	0.012	0.026
Second	1961	0.071	0.032	0.056	0.047	0.102
8-foot log	1977	0.482	0.223	0.197	0.094	0.156
Entire	1961	0.031	0.018	0.024	0.021	0.045
16-foot log	1977	0.244	0.112	0.099	0.048	0.083

Summary and Conclusions

The results presented here represent only one age and one size class and apply only to white oak. More comprehensive studies must be completed across a broad range of age, site, and species before specific recommendations can be offered. However, the data suggest that the effect of stocking on potential stem quality may be substantial. The findings in this study indicate that:

1. The number of limb-related defects decreases with increasing residual stand density.
2. The size of live limbs decreases in both upper and lower 8-foot logs with increasing residual stand density.
3. Live limbs generally are larger in the upper log.
4. In this relatively young pole timber stand, there are still more living than dead branches on the 16-foot log, regardless of the residual basal area.
5. The average number of branch-related defects on the butt 16-foot log decreases from a high of nine per tree at the lowest stocking to one to three on the higher stocked plots.
6. The number of epicormic branches on both the lower and upper 8-foot sections generally have decreased since 1961 because many have grown to branch classification size. However, epicormic branches still are numerous on both sections after 16 years, regardless of stand density, and remain a potential source of future defects.

Extremely heavy initial thinning in these young oak stands certainly delays, if not substantially reduces, the potential to develop high-quality stems. Except for extremely heavy thinning, the residual density does not seem to markedly affect stem quality. If sufficient trees are left to fully use the sites (about 60 percent or more stocking, Roach and Gingrich 1968) any slight loss in quality may be compensated for by trees growing faster or reaching maturity sooner than those in unthinned stands. More study is needed on growth, quality, and economic factors before specific thinning regimes can be recommended for the white oak timber type. Meanwhile, it appears from this study that tree quality will not be seriously affected so long as stocking is 50 percent or more after thinning.

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Relative changes in several types of stem defects were studied over a 16-year period to determine the effect of thinning intensity on the development of tree quality. Sixty-six sample white oak crop trees represented each of five density levels created by thinning a young white oak stand in Kentucky in 1961. Occurrence of branch-related and other stem defects on the butt 16-foot section was studied from stereo pairs of photographs taken in 1961 and 1977. The number of live and dead branches greater than 0.3 inch in basal diameter increased on all density plots. Except for extremely heavy thinnings, those below C-level stocking, tree quality was not markedly affected by residual stand density.

ODC 228.1:242:851:852.11

Keywords: Silviculture; thinning; bole quality

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United States
Department of
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**Northeastern Forest
Experiment Station**

Research
Paper NE-540

1984

Costs of Reducing Sapling Basal Area in Thinned Cherry-Maple Stands in West Virginia

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Manuscript received for publication 16 November 1983

Abstract

Unmanaged 60-year-old cherry-maple stands in West Virginia were thinned to three levels of stocking according to the Allegheny hardwoods stocking guide. After the merchantable timber was removed, the basal area in saplings was reduced to less than 10 ft^2/per acre (2.3 m^2/ha), as the guide recommends for stands with dense understories. A detailed time study revealed that cutting saplings with chain saws costs about $17.00 per acre ($42/ha). This amount may be recoverable in increased yield, tax deductions, and fuelwood sales.

Cover Photo

Saplings were felled by experienced loggers.

Introduction

The stocking guide for Allegheny hardwoods recommends thinning even-aged stands to 60 percent of full stocking, the minimum stocking theoretically needed to utilize the site fully (Roach 1977). Other stocking guides developed for eastern forest types have similar residual stocking recommendations, but none of the guides, including the guide for Allegheny hardwoods, support their recommendations with actual response data (Leak 1981). As part of a large thinning study designed to test and refine the Allegheny hardwoods stocking guide for use in West Virginia, the implications of reducing sapling basal area as recommended by the guide were examined.

In addition to providing general guidelines on residual stand density, the Allegheny guide makes specific recommendations for distributing the cut among species groups and size classes, including saplings, defined as stems 1.0 to 5.5 inches (2.5–14.0 cm) dbh. Of particular concern from an economic standpoint is the recommendation to greatly reduce sapling basal area in stands with relatively dense understories. The economic impact of sapling removal depends on the cost of the treatment and the response of the residual trees in the stand. Net revenues from commercial thinnings can be quickly eroded by operations in the nonmerchantable portion of the stand. Without sufficient increases in the growth of residual trees, sapling removal will not only reduce net revenues of commercial thinning, but will also reduce net present value of timber production on the area.

Some recent studies have shown that reducing understory basal area in thinned hardwood stands increases the growth of residual trees in the overstory. Dale (1975) found that thinned upland oak stands with all woody stems less than 1.6 inches (4.1 cm) dbh eradicated grew faster than stands similarly thinned but with the understory left in place over a 10-year period. Karnig and Stout (1969) found that understory removal after a heavy thinning resulted in a slight increase in basal area growth of red oak over three growing seasons. Although these studies showed that understory removal in conjunction with thinning increases the growth of residual trees, cost and return data were not available to evaluate its economic feasibility.

This report provides cost indicators and discusses the economic and silvicultural implications of sapling removal as a separate stand treatment following commercial logging. Data were collected in cherry-maple (*Prunus serotina* Ehrh.—*Acer rubrum* L.) stands in West Virginia, but the information can be helpful wherever stocking guides are used to control intermediate cuttings in hardwood stands.

The Study Area

The study was conducted in the Middle Mountain area of the Monongahela National Forest. Treated stands were previously unmanaged even-aged black cherry-maple stands about 60 years old. The study area is representative of about 125,000 acres (50,600 ha) of commercial forests in north central West Virginia and resembles the Allegheny hardwood forests of northwestern Pennsylvania: rainfall averages about 55 to 60 inches (1.4–1.5 m) per year; site index for black cherry is 75 feet (23 m). The terrain in the immediate study area is gentle rolling hills with slopes generally less than 10 percent.

The overstory was primarily black cherry and red maple with some white ash (*Fraxinus americana* L.). The understory was made up of American beech (*Fagus grandifolia* Ehrh.), red maple, and sugar maple (*Acer saccharum* Marsh.). Based on a complete inventory of all trees 1.0 inch (2.5 cm) dbh and larger on eighteen ½-acre (0.2 ha) plots, the average basal area was 164 ft^2 per acre (38 m^2/ha) with 69 percent of the basal area in the cherry, ash, yellow-poplar (*Liriodendron tulipifera* L.) (CAPs) species group. Basal area in saplings averaged 25 ft^2 per acre (5.7 m^2/ha). The study area also averaged 826 trees per acre with an average diameter of 6.0 inches (15.2 cm). According to the stocking chart (Roach 1977), the area was about 110 percent stocked before thinning.

In merchantable trees 7.0 inches (17.8 cm) dbh and larger, the study area averaged 216 trees per acre (534/ha) with an average diameter of 10.4 inches (26.4 cm) dbh.

Plot Treatments

Eighteen 2-acre (0.8 hectare) experimental units were randomly divided among three thinning densities, 75, 60, and 45 percent of full stocking. Each 2-acre unit was marked as recommended in the Allegheny hardwoods stocking guide (Roach 1977). For example, two-thirds of the basal area cut was below the average diameter in each species group (CAPs and others). Saplings as well as poles and sawtimber were marked. Although marking in the poles and sawtimber varied with the target density, the marked cut for saplings was essentially the same for all thinning densities, averaging 16 ft^2 of basal area per acre (3.7 m^2/ha) in the 18 plots.

Calculations were based on a complete inventory of all trees 1.0 inch dbh (2.5 cm) and larger on a ½-acre (0.2 hectare) measurement plot located within each 2-acre unit. Trees not marked for cutting in the ½-acre measurement plot were tagged for long-term study.

Six 2-acre units, two from each thinning density, were logged in the fall of 1981. All marked trees 7.0 inches dbh (17.8 cm) and larger were cut and skidded. No trees smaller than 7.0 inches dbh were cut in these six units.

Twelve 2-acre units, four from each thinning density, were logged in the spring of 1982. After all marked trees 7.0 inches dbh and larger had been removed, marked trees smaller than 7.0 inches dbh were cut. These included marked saplings and marked nonmerchantable poles 5.6 to 6.9 inches (14.2–17.5 cm) dbh. This part of the thinning was carried out as a separate operation.

Data Collection

Cost data collected from these 12 thinning units included fuel usage, machine-hours, and man-hours. On five plots, man-hours were measured by the detailed time study method. The activities of workers were divided into work cycles and the cycles were subdivided into cycle elements. An observer recorded each element as it occurred without missing any time between successive elements.

Work cycle elements were classified as either productive elements or delay elements. Productive elements included WALK, SWAMP, and FELL. Delay elements included REFUEL, REPAIR SAW, WAIT, REST, and PERSONAL. The characteristic beginning and ending points of each element were defined to allow for consistency in the timing procedure.

Gross job time and the number of stems cut were recorded for each of the twelve 2-acre units. On the five time-study units, gross time was determined as the sum of all cycle times and the number of stems cut equaled the number of cycles. On the other seven treatment units, the number of cut trees was estimated from inventories of the ½-acre measurement plot within each unit.

Results

Cost Per Tree

A total of 632 trees were felled during the detailed time study. Productive time plus delay time totaled about 430 minutes of work. The bulk of productive time was spent walking from tree to tree, while swamping time was nearly negligible (Table 1). Delays amounted to 38 percent of the total job time, and half of the delay time was spent refueling, repairing, and servicing the chain saws. Another 35 percent of the delay time was spent resting.

The average time required to cut saplings under the conditions studied was 0.68 minutes per tree, counting delays. Gabriel and Nissen (1974) obtained similar results in New York. However, cutting saplings and small poles in the 45 percent treatment required about 0.76 minutes per tree, because the abundance of slash and tops made walking from tree to tree more difficult (Table 2). The actual dollar cost per tree depends on the size of the trees included in the cut, the intensity of the cut, and the hourly cost of labor and equipment.

Table 1.—Time in minutes for productive activities: cutting nonmerchantable stems after logging

Dbh class (inches)	No. stems	Percent	Elements			Total	Percent	Mean time per stem
			Walk	Swamp	Fell			
4	273	43	58.9	0.8	38.5	98.2	37	0.36
5	205	32	49.4	1.3	38.7	89.4	33	0.44
6	117	19	27.7	1.8	29.3	58.8	22	0.50
7	37	6	8.6	1.0	11.6	21.2	8	0.57
Total	632	100	144.6	4.9	118.1	267.6	100	0.42
Percent			54	2	44	100		

Table 2.—Time required to cut nonmerchantable stems after logging in the three thinning treatments

Treatment: percent stocking	Stocking before sapling cut	Cut required to reach desired stocking		Cutting time per tree	Total time per acre
	%	*Stems/acre*[a]	*BA/acre*(ft²)[b]	*min*	*hr*[a]
75	91	150	20	0.65	1.63
60	76	150	20	0.66	1.65
45	58	130	17	0.76	1.65

[a]For stems per hectare multiply stems per acre by 2.47.
[b]For m² per hectare multiply ft² per acre by 0.23.

Cost Per Hour

The machine costs presented here are based on a new McCulloch Pro Mac 800[1] with a 24-inch bar. The fixed cost, including depreciation and interest, insurance, and taxes was $0.43 per hour (Miyata 1980). The operating cost was $1.51 per hour. The total labor cost, including a wage of $5.50 per hour and 28 percent mandatory fringe benefits, was $7.04 per hour. The hourly machine cost will differ for different chain saws and the labor cost could differ with location. Total cost under the conditions studied was $8.98 per scheduled hour of work.

Cost Per Acre

The cost per acre to cut saplings and nonmerchantable stems was nearly equal in the three treatments. In the 75 and 60 percent treatments, the cut required to reach the target level of stocking was 20 ft^2 of basal area per acre (4.6 m^2/ha), roughly 150 trees (Table 2). This required about 1.64 hours at a cost of $14.58 per acre. In the heavily thinned plots, the cut required to reach 45 percent residual stocking was less, only 17 ft^2 per acre (3.9 m^2/ha). Because the cutting time per tree was higher in the 45 percent treatment, its cost was about the same as the other treatments, $14.82 per acre. A contractor or consulting forester hired to cut nonmerchantable stems would require a margin of profit to complete the operation. A 15 percent margin for profit and risk brings the total treatment cost to about $17.00 per acre ($42.00 per hectare).

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Silvicultural Implications

Ignoring the saplings and other nonmerchantable stems when thinning hardwood stands can lead to a silvicultural dilemma. If the stands are marked according to the stocking guide, with nonmerchantable stems included in the mark but not actually cut, the residual stands would have a higher percentage stocking than desired. In plots targeted for a 60 percent thinning, residual stocking was 76 percent before the saplings and nonmerchantable stems were cut (Table 2). At this level of stocking mortality begins to increase, reducing net growth and the rate of product development (Roach 1977). Growth is distributed among many trees, some of it wasted on trees that will die before the next cut.

On the other hand, if desired stocking is achieved by heavier cutting in the merchantable size classes, the dominant and codominant crop trees will be overcut. Mortality would not be a problem until the stand reached about 80 percent stocking, but growth would be concentrated on smaller stems (Roach 1977). As a result, board foot volume production would be reduced and the big dollar yield at rotation age would be delayed.

In stands with sparse understories, less than 20 ft^2 per acre (4.6 m^2/ha) in saplings, the effect of saplings in the marked cut is slight. However, in stands with dense understories, saplings and nonmerchantable poles should be included in the cut to achieve a balanced and effective thinning.

Economic Implications

The purpose of thinning these 60-year-old stands was to concentrate growth on the best trees in the stand, increase yield by salvaging trees that would die, and reduce the time required for the stand to reach physical maturity. Thinning merchantable stems reduces overstory competition and leads to faster growth of residual crop trees. If reducing sapling basal area further stimulates the growth of residual crop trees, then cutting saplings could produce a net economic gain.

For sapling cutting to be profitable, stands so treated must provide increased dollar yields in later thinnings and final harvest that exceed the cost of sapling removal. Increases in dollar yields, if any, will most likely be from improved tree quality or increased board foot yields, or both. An example shows that the additional yield required (over stands that were only thinned) is not unreasonable (Table 3).

The example presented deals with after-tax cash flows. Because the cost of noncommercial thinning in established stands may be deducted as an operating expense, the actual cost of sapling removal is determined by the landowner's marginal tax rate (U.S. Forest Service 1982; Weston and Brigham 1981). The example assumes a marginal tax rate of 25 percent, resulting in an after-tax cost of $12.75 per acre ($31.49/ha) for cutting saplings. Other assumptions include an average annual inflation rate of 5 percent and no real change

in stumpage prices over the investment period. Three investment periods were considered.

If 9 percent is the alternative market rate of return, the sapling cut must result in added revenue of $47.08 per acre ($116.29/ha) from a final harvest 20 years after thinning. This means that annual growth must increase by about 17 bf (International ¼-inch rule) per acre (0.24 m^3/ha), roughly 6 percent of current annual growth, to equal the alternative investment.

The actual growth capabilities of stands treated this way are not known, but growth responses and quality changes will be monitored over the next 20 years. We know that saplings are important in determining stand stocking and that treatment costs do not require unreasonable growth increases to justify sapling removal in stands with dense understories. Periodic remeasurement of the residual trees will disclose how much of the treatment costs will be offset by increased board foot yields as the stand nears final harvest.

The cost of cutting nonmerchantable stems can be reduced by selling some of the material as fuelwood. The average volume available for sale as fuelwood from the 12 treated plots was about 8 cords per acre (6.2 m^3/ha). If fuelwood brought $2 per cord on the stump, such a sale could offset the cost of the treatment. Actual fuelwood revenues, however, would depend on accessibility of the product and local fuelwood markets.

Table 3.—Additional dollar and board foot yields needed to earn selected rates of return from cutting saplings in stands thinned to 60 percent residual stocking

Required return[a]	10 years		20 years		30 years	
	Value yield	Volume yield[b]	Value yield	Volume yield	Value yield	Volume yield
Percent	*$/acre*[c]	*bf/acre*[c]	*$/acre*	*bf/acre*	*$/acre*	*bf/acre*
5.25	18.76	213	27.60	193	40.61	174
7.50	22.04	251	38.09	266	65.84	282
9.00	24.50	279	47.08	329	90.48	388

[a]Converted to after-tax rates before computing required yields.
[b]Stumpage revenues were treated as capital gains to determine after-tax volume yields needed to earn selected rates of return.
[c]For $ per hectare multiply $ per acre by 2.47.
For m^3 per hectare multiply bf per acre by 0.014.

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Unmanaged 60-year-old cherry-maple stands in West Virginia were thinned to three levels of stocking according to the Allegheny hardwoods stocking guide. After the merchantable timber was removed, the basal area in saplings was reduced to less than 10 ft^2 per acre, as the guide recommends for stands with dense understories. A detailed time study revealed that cutting saplings with chain saws costs about $17.00 per acre. This amount may be recoverable in increased yield, tax deductions, and fuelwood sales.

ODC 242:323.2:535

Keywords: cost data, sapling removal, thinning, stocking, northern hardwoods

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984—705-029/505

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Paper NE-541

1984

Residual Stocking not Seriously Reduced by Logging Damage from Thinning of West Virginia Cherry-Maple Stands

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Abstract

In north-central West Virginia, unmanaged 60-year-old cherry-maple stands were thinned to 75, 60, and 45 percent residual stocking. Cut trees were skidded tree length by a rubber-tired skidder. Logging destroyed or severely bent over 22, 23, and 45 percent of the unmarked stems in the 75, 60, and 45 percent stocked plots. Because 99 percent of the destroyed and bent trees were less than 5.0 inches dbh, the effect on basal area and residual stocking was slight. Damage reduced the stocking by 5, 8, and 8 percent in the 75, 60, and 45 percent plots. For the 75, 60, and 45 percent plots, 18, 38, and 42 percent of the residual stems received wounds that exposed sapwood. Study results indicate that marking guidelines for trees larger than 5.0 inches dbh do not need to be adjusted to account for logging damage.

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Manuscript received for
publication 17 October 1983

Introduction

Each time the forest is cut, some residual trees are damaged. Damage may include complete destruction of a potential crop tree, broken branches, or exposed sapwood. An important question in thinning even-aged stands is: Should an allowance be made in marking for logging damage to residual stems? This paper reports on damage to residual trees resulting from thinning even-aged cherry-maple (*Prunus serotina* Ehrh.-*Acer rubrum* L.) stands in West Virginia to three levels of residual stocking with a rubber-tired skidder.

The Study Area

The study area is located on Middle Mountain in the Monongahela National Forest in north central West Virginia. Treated stands were previously unmanaged even-aged cherry-maple stands about 60 years old. In trees at least 1.0 inch in dbh, the stands averaged 881 trees per acre, with a basal area of 165 ft^2 per acre, a cubic foot volume of 2,854 ft^3 per acre for trees at least 5.0 inches in dbh, and a board foot volume (International) of 7,314 fbm per acre for trees at least 11.0 inches in dbh. The study area is representative of about 125,000 acres of commercial forest land in the area and resembles the Allegheny hardwood forests of northwestern Pennsylvania. The terrain of the study area was nearly flat.

Data

As part of a large study to test the applicability of the Allegheny hardwoods stocking guide (Roach 1977) in this region, 2-acre plots were thinned to 75, 60, and 45 percent residual stocking. Twelve plots, 4 thinned to each level, were included in this portion of the study. Within each 2-acre plot, an observation plot of ½ acre was installed. After the 2-acre plots were marked for thinning, all residual trees at least 1.0 inch in dbh on the observation plots were permanently identified. Each tree was carefully examined for wounds resulting from natural causes before logging. Species, diameter, and crown class of each residual tree were also recorded before logging.

The plots were logged by a three-man crew using chain saws and a rubber-tired skidder. One man felled and topped trees to a 6-inch dib while the other two skidded tree-length logs to the decking area. Trees 3.6 inches dbh and larger were marked; however, those less than 7.0 inches dbh were cut but not skidded from the plots. Up to nine chokers were used per hitch with the skidder permitted to run throughout the plot. Trees from one 2-acre plot were not skidded through other plots. Felling and skidding started at the back of each plot and proceeded toward the main skid road or deck. Trees were directionally felled whenever possible, although the dense stands and level terrain made it impossible to fell all of the trees directionally.

All logging operations were done in the spring of the year when the bark was slipping and logging damage to residual trees could be expected to be greatest. After logging, each residual tree on the observation plots was carefully examined for logging injuries. Four types of injuries were noted: 1) completely destroyed (Figures 1, 2, and 3); 2) bent over or severely leaning; 3) exposed sapwood; 4) broken tops. The length and width of each wound that exposed sapwood were measured.

Results

Two types of damage, destroyed trees and bent or severely leaning trees, reduced the number of residual trees and lowered the residual stand stocking below the desired level. In the following discussions, these types of damage are expressed as a percentage of the unmarked portion of the stand. Conversely, damage involving exposed sapwood and broken tops affected only the quality of the residual trees and did not affect stand stocking. These types of damage are expressed as a percentage of the net residual stand—the unmarked stand minus destroyed and bent or severely leaning stems.

Figure 1.—Saplings destroyed during skidding.

Figure 2.—Saplings bent over during skidding.

Figure 3.—Exposed sapwood wound.

Destroyed

For the 75, 60, and 45 percent residual stocking plots, 11, 22, and 30 percent of the unmarked trees were destroyed by logging. Because most of the destroyed trees (99 percent) were less than 5.0 inches dbh, residual basal area was not seriously reduced. Only 2, 4, and 5 percent of the unmarked basal area was destroyed by logging in the 75, 60, and 45 percent stocked plots (Tables 1, 2, 3), resulting in plots with an actual stocking of 69, 53, and 37 percent after logging.

Bent Over or Leaning

For the 75, 60, and 45 percent stocking levels, a total of 72, 64, and 70 stems per acre were bent over or left leaning by logging. Ninety-nine percent of these trees were less than 5.0 inches dbh. This form of damage amounted to 12 percent of the unmarked stems and about 2 percent of the unmarked basal area (Tables 1, 2, and 3). Although these injuries did not kill the trees, such trees often die soon from snow and ice damage.

Exposed Sapwood

In the plots with 75 percent residual stocking, 18 percent of the residual stems comprising 25 percent of the residual basal area had damage that exposed sapwood (Table 1). In the plots with 60 percent residual stocking, 38 percent of the residual stems comprising 43 percent of the residual basal area had exposed sapwood (Table 2). Sapwood damage was most severe in the 45-percent-residual-stocking plots. Forty-two percent of the residual stems comprising 56 percent of the basal area had exposed sapwood in the heavy thinning treatment (Table 3). Thus, there was a direct relation between exposed sapwood and intensity of thinning: as the number of stems and basal area removed increased, sapwood was exposed on more trees.

Table 1.—Summary of logging damage in plots thinned to 75 percent residual stocking.

	Stems per acre, by dbh class				Basal area per acre (ft²), by dbh class				Percent stocking
	1.0–4.9 in	5.0–10.9 in	11+ in	Total	1.0–4.9 in	5.0–10.9 in	11+ in	Total	
Initial stand	602	266	55	923	22.0	87.2	54.0	163.2	111
Marked cut	120	135	7	262	11.9	35.8	5.7	53.4	
Unmarked stand[a]	482	131	48	661	10.1	51.4	48.3	109.8	74
Bent over or leaning	71	1	0	72	1.5	0.1	0	1.6	
Destroyed	74	1	0	75	1.5	0.3	0	1.8	
Net residual stand[b]	337	129	48	514	7.1	51.0	48.3	106.4	69
Exposed sapwood	47	30	14	91	1.3	12.4	12.4	26.1	
Broken top	15	0	0	15	0.3	0	0	0.3	

[a]Unmarked stand = initial stand – marked cut.
[b]Net residual stand = unmarked stand – (destroyed + bent over or leaning).

Table 2.—Summary of logging damage in plots thinned to 60 percent residual stocking.

	Stems per acre, by dbh class				Basal area per acre (ft^2), by dbh class				Percent stocking
	1.0–4.9 in	5.0–10.9 in	11+ in	Total	1.0–4.9 in	5.0–10.9 in	11+ in	Total	
Initial stand	552	298	55	905	22.2	99.4	46.9	168.5	115
Marked cut	130	200	13	343	12.0	58.6	10.1	80.7	
Unmarked stand[a]	422	98	42	562	10.2	40.8	36.8	87.8	61
Bent over or leaning	63	1	0	64	1.4	0.2	0	1.6	
Destroyed	119	2	1	122	2.5	0.7	0.4	3.6	
Net residual stand[b]	240	95	41	376	6.3	39.9	36.4	82.6	53
Exposed sapwood	79	45	17	141	1.7	19.1	14.7	35.5	
Broken top	38	0	1	39	0.4	0	0.4	0.8	

[a]Unmarked stand = initial stand − marked cut.
[b]Net residual stand = unmarked stand − (destroyed + bent over or leaning).

Table 3.—Summary of logging damage in plots thinned to 45 percent residual stocking.

	Stems per acre, by dbh class				Basal area per acre (ft^2), by dbh class				Percent stocking
	1.0–4.9 in	5.0–10.9 in	11+ in	Total	1.0–4.9 in	5.0–10.9 in	11+ in	Total	
Initial stand	489	275	63	826	19.5	93.0	53.4	166	107
Marked cut	106	229	22	357	10.2	72.3	17.2	99.7	
Unmarked stand[a]	383	46	41	469	9.3	20.7	36.2	66.3	45
Bent over or leaning	69	1	0	70	1.4	0.1	0	1.5	
Destroyed	140	1	0	141	3.2	0.4	0	3.6	
Net residual stand[b]	174	44	41	258	4.7	20.2	36.2	61.2	37
Exposed sapwood	61	21	27	109	1.9	10.0	22.3	34.2	
Broken top	21	1	1	23	0.5	0.4	1.3	2.2	

[a]Unmarked stand = initial stand − marked cut.
[b]Net residual stand = unmarked stand − (destroyed + bent over or leaning).

An important factor in sapwood damage is the size of the wounded tree. In this study, the percentage of residual trees with exposed sapwood increased with heavier thinning. The distribution of sapwood damage among size classes, however, remained about the same in each treatment. About 55 percent of the wounded trees were less than 5.0 inches dbh and 83 percent were less than 11.0 inches dbh.

Broken Tops

A few residual trees suffered broken tops during logging (Tables 1, 2, and 3). The most damage occurred in the heavily thinned plots (45 percent residual stocking), where 9 percent of the residual trees sustained broken tops. In the plots with 60 percent and 75 percent residual stocking, 10 percent and 3 percent of residual trees, respectively, sustained broken tops. Nearly all trees (96 percent) with this type of injury were less than 5.0 inches dbh, so a very small portion of the residual basal area was affected by top damage.

Effect on Residual Stand Stocking

The stands were marked according to the Allegheny hardwoods stocking guide (Roach 1977) with no allowance for logging damage to the residual stand. Trees that were bent over were included with destroyed trees in calculating the stocking of the residual stand (Tables 1, 2, and 3). Residual stand stocking was reduced 5, 8, and 8 percent by logging damage in the 75, 60, and 45 percent residual stocking areas, respectively (Tables 1, 2, and 3). About 99 percent of the destroyed or bent over trees were less than 5.0 inches dbh.

Discussion

The results of this study are about the same as those of other studies of logging damage in upland hardwood even-aged and uneven-aged stands. In partial cuts made with a rubber-tired skidder or crawler tractor with a rubber-tired arch skidding tree-length logs, seriously injured or destroyed trees amounted to less than 10 percent of the residual basal area in the stand. This damage was concentrated in the sapling size class (Weitzman and Holcomb 1952, Herrick and Deitschman 1956; Nyland and Gabriel 1972).

The thinning treatment currently recommended[1] for these stands is to reduce the residual stand stocking to about 60 percent. In stands with 20 or more square feet of basal area in trees 1 to 5 inches dbh, it is further recommended that sapling basal area be reduced to less than 10 ft^2 per acre. If thinned to 60 percent residual stocking, about 35 to 40 percent of the residual stems will receive injuries that result in exposed sapwood. Over half of the wounded trees will be less than 5.0 inches in dbh.

[1]Allegheny hardwoods silviculture training course. Northeastern Forest Experiment Station, Forestry Sciences Laboratory, Warren, PA.

Size of exposed sapwood wounds is an important factor. Research has shown that wounds with over 100 in^2 of exposed sapwood are likely to develop decay (Hesterberg 1957; Lavallee and Lortie 1968). Lamson and Miller (1983) found that in these same stands logged with the wheeled skidder, about 7, 13, and 22 percent of the residual dominant and codominant stems had exposed sapwood wounds of at least 100 in^2 in plots with 75, 60, and 45 percent residual stocking, respectively. In other words, it appears that most of the sapwood wounds on potential crop trees are small enough to heal with little danger of sapwood decay. Also, many of the trees with large sapwood wounds can be removed in future thinnings.

When trees bent over or leaning are combined with destroyed trees in the plots with 60 percent residual stocking, the total damage accounts for only about 6 percent of the basal area. Residual stand stocking was reduced 8 percent by this type of damage. Because most of the losses occurred in trees less than 5.0 inches in dbh, competition for light among dominant, codominant, and intermediate trees was not influenced by logging damage.

Conclusions

From this study, the following conclusions can be stated about thinning 60-year-old cherry-maple stands in northern West Virginia.

1. At three thinning levels, providing 75, 60, and 45 percent residual stocking, logging damage was concentrated in trees less than 5.0 inches dbh.
2. At 60 percent residual stocking:
   a. Logging injuries that result in exposed sapwood were found on 38 percent of the residual trees and about 88 percent of these injured trees were less than 11.0 inches dbh.
   b. Logging damage that resulted in destroyed or bent over trees reduced the stocking only about 8 percent.

Recommendations

1. In stands with less than 20 ft^2 of basal area per acre in trees less than 5.0 inches dbh, marking guidelines do not need to be adjusted to account for logging damage.
2. In stands with more than 20 ft^2 of basal area per acre in trees less than 5.0 inches dbh, reduce the marked cut in saplings by 5 to 10 stocking percentage points to account for logging damage.
3. Marking guidelines for trees over 5.0 inches dbh do not need to be adjusted to account for logging damage.

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In north-central West Virginia, unmanaged 60-year-old cherry-maple stands were thinned to 75, 60, and 45 percent residual stocking. Cut trees were skidded tree length by a rubber-tired skidder. Logging destroyed or severely bent over 22, 23, and 45 percent of the unmarked stems in the 75, 60, and 45 percent stocked plots. Because 99 percent of the destroyed and bent trees were less than 5.0 inches dbh, the effect on basal area and residual stocking was slight. Damage reduced the stocking by 5, 8, and 8 percent in the 75, 60, and 45 percent plots. For the 75, 60, and 45 percent plots, 18, 38, and 42 percent of the residual stems received wounds that exposed sapwood. Study results indicate that marking guidelines for trees larger than 5.0 inches dbh do not need to be adjusted to account for logging damage.

ODC 242:461:535:176.1

Keywords: Logging damage; thinning; stocking

U.S. GOVERNMENT PRINTING OFFICE: 1984—705-029/506

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**Northeastern Forest
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Paper NE-542

1984

System 6:
Rough-Mill Operating Manual

Hugh W. Reynolds

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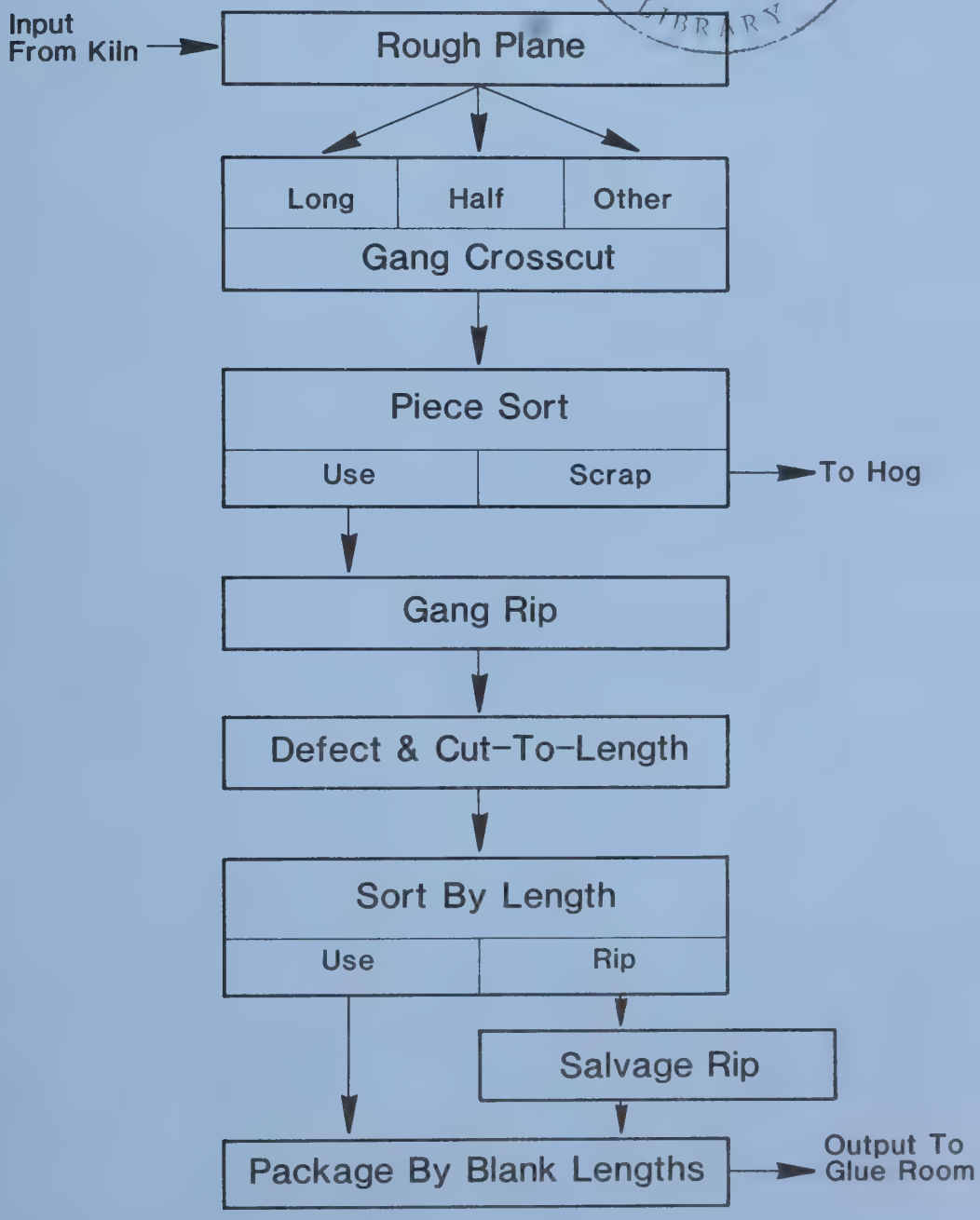

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Manuscript received for
publication 14 September 1983

Abstract

Includes operating instructions for the System 6 rough mill. Techniques are shown for making standard-size blanks, in all lengths, for each of 13 blank quality/width/thickness combinations.

The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program.

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Introduction

System 6 is a new technology used to convert low-grade, small-diameter hardwood timber to edge-glued panels for use by the furniture and kitchen cabinet industries. In System 6 (Fig. 1), trees are made to bolts, bolts are sawed to cants, cants are resawed to boards, boards are air dried and then kiln dried, the kiln-dried boards are cut up to defect-free pieces, and the pieces are edge-glued to make standard-size panels (blanks).

The marketing aspects of System 6 were outlined by Reynolds and Gatchell (1979). The technology was explained by Reynolds and Gatchell (1982). The use of System 6 to make upholstered frame parts for the furniture industry (Reynolds and Araman 1983) and to make parts for the kitchen cabinet industry also has been studied (Reynolds et al. 1983).

The output of a System 6 plant is edge-glued panels. These panels are called standard-size blanks (Araman et al. 1982). Blanks are made or purchased by furniture and cabinet makers and are ripped and trimmed to the required part sizes. Parts made from blanks cost no more than parts made in the conventional manner from lumber. However, buying green lumber and making parts requires facilities for air and kiln drying, rough milling, and edge gluing; using blanks to make parts requires just a ripsaw and a trimsaw.

In this paper I explain how the System 6 rough mill—where the kiln-dried boards are made to standard-size pieces free of objectionable defects—is operated. Blanks of only one quality, width, and thickness are made in each run. To set up the rough mill for a run, the quality, width, and thickness must be specified. The heart of the System 6 rough mill is the gang crosscut saw. The spacings of the gang crosscut saw (GCL's) are set to obtain the lengths of blanks required. I explain how this information on blanks and GCL is used to operate the rough mill to obtain the desired blanks in the required lengths.

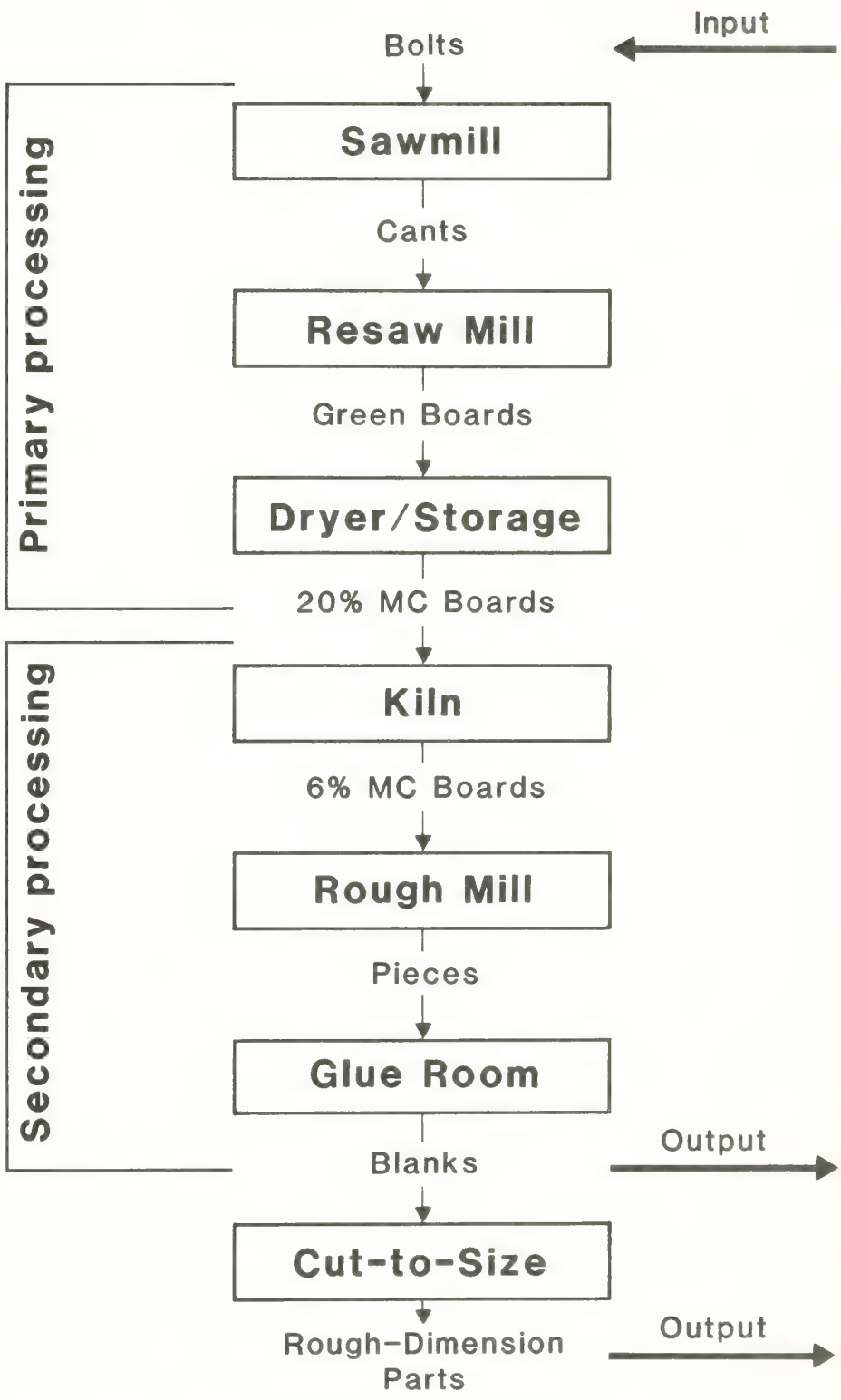

Figure 1.—Flowchart of System 6.

Blanks

Standard-size blanks are pieces of solid wood, free of objectionable defects, of standard lengths, edge-glued to standard-width panels. The standard sizes were derived by Araman et al. (1982). Blanks are made in four qualities, two widths, and six thicknesses. Not all qualities of blanks are made in both widths and in all thicknesses. There are only 13 blank quality/width/thickness combinations:

- Clear (C1F and C2F)[1] blanks: 26-inch width only; 5/8-, 3/4-, 4/4-, 5/4-, 6/4-, 8/4-inch thickness (six quality/width/thickness combinations).
- Frame[2] blanks: 20-inch width only; 4/4-, 5/4-, 6/4-, 8/4-inch thickness (four quality/width/thickness combinations).
- Core[3] blanks: 26-inch width only; 4/4-, 5/4-inch thickness (two quality/width/thickness combinations).
- Interior[4] blanks: 20-inch width only; 4/4-inch thickness only (one quality/width/thickness combination).

There are 148 quality/width/thickness/length combinations. The following tabulation shows the lengths of standard-size blanks, by quality, width, and thickness:

Thickness	Clear (1 and 2 face) Quality (26-inch width)												
5/8	13	15	17	18	22	26	31	36	42				
3/4	14	17	18	22	25	29	31	35	41	47	58	86	
4/4	15	18	21	25	29	33	38	45	50	60	75	100	
5/4	15	18	21	25	29	33	38	45	50	60	75	100	
6/4	15	18	21	25	28	32	35	40	45	50	60	70	85
8/4	15	18	21	25	28	32	35	40	45	50	60	70	90
Thickness	**Core Quality (26-inch width)**												
4/4	15	18	21	23	26	29	34	40	50	60	70	90	
5/4	15	18	21	23	26	29	34	40	50	60	70	85	
Thickness	**Frame Quality (20-inch width)**												
4/4	13	17	19	22	24	27	29	33	44	54	70	80	100
5/4	15	18	20	23	25	28	33	45	55	65	80	90	100
6/4	14	18	21	24	28	31	34	40					
8/4	12	16	19	21	24	28	30	40					
Thickness	**Interior Quality (20-inch width)**												
4/4	15	18	21	25	29	34	40	50	60	70	95		

In operating the System 6 rough mill, only 1 of the 13 quality/thickness/width combinations is made at a time and all of the standard lengths are made. As an example, clear-quality blanks that are 26 inches wide and 4/4 inches thick would be made in all 12 lengths in one rough mill run. The same 12 lengths are used when changing to the production of clear-quality blanks that are 26 inches wide and 5/4 inches thick. The rough-mill setup would not have to be changed when switching from 4/4 to 5/4 clear blank production. The only change would be to substitute 5/4 for 4/4 input boards.

Of the 13 standard quality/width/thickness combinations, 2 combinations, 4/4 and 5/4 clear blanks, have the same 12 lengths. The 6/4 and 8/4 clear-blank combinations have the same lengths except for the longest length. This is true for the two core quality combinations. These similarities allow us to combine the 13 blank quality/width/thickness combinations into 10 quality/width/length combinations.

These 10 combinations are designated A through J for convenience. The rough mill will be operated with only one of these combinations at a time. Nine such rough-mill operating combinations are needed to provide all of the blanks required by the furniture industry; three combinations are needed for the kitchen cabinet blanks (Tables 1-2).

[1]C1F (clear-one-face): This material shall be clear on one face, both edges, and both ends, and shall otherwise comply with clear-two-face quality except that the reverse face may contain defects of sound quality (from Hardwood Dimension Manufacturers Association 1961). C2F (clear-two-face): This material shall be clear on both faces, the edges, and the ends except that sapwood, slight streaks, and small burls or swirls and light stain are permitted (HDMA 1961).

[2]Frame quality: No defects within 1 inch of either end. Defects within each piece are limited to one-half the piece width with no more than one such defect per foot of piece length. Wane may not be on more than one edge, may not be more than half the piece thickness, and may not extend more than half the piece length. No shake or split longer than 1 inch permitted. Rot and unsound wood not permitted (HDMA 1961).

[3]Interior quality: No defects within 1 inch of either end. Defects within each piece are limited to one-half the piece width with no more than one such defect per foot of piece length. No shake or split longer than 1 inch permitted. Rot and unsound wood not permitted (HDMA 1961).

[4]Core quality: This material shall be sound on both faces admitting tight sound knots, small worm holes, slight surface checks, or their equivalent (HDMA 1961).

Table 1.—Rough-mill operating blank quality/width/length combinations for furniture industry blanks (A is most used, B is next most used, etc.)

Thickness (inches)	Clear quality (26-inch width)	Frame quality (20-inch width)	Interior quality (20-inch width)	Core quality (26-inch width)
5/8	G	NR[a]	NR	NR
3/4	NR	NR	NR	NR
4/4	A	B	D	E
5/4	A	F	NR	E
6/4	C	I	NR	NR
8/4	C	H	NR	NR

[a]Not required.

Table 2.—Rough-mill operating blank quality/width/length combinations for kitchen cabinet industry blanks (A is most used, D is next most used, J is least used)

Thickness (inches)	Clear quality (26-inch width)	Frame quality (20-inch width)	Interior quality (20-inch width)	Core quality (20-inch width)
5/8	NR[a]	NR	NR	NR
3/4	J	NR	NR	NR
4/4	A	NR	D	NR
5/4	A	NR	NR	NR
6/4	NR	NR	NR	NR
8/4	NR	NR	NR	NR

[a]Not required.

The Rough Mill

A System 6 rough mill (Fig. 2) is much different from a conventional rough mill used to convert high-quality hardwood lumber to rough-dimension parts. In the System 6 rough mill all boards are used to make blanks. First, rapid and efficient automated breakdown of the boards (gang crosscutting is followed by gang ripping) removes the major defects. Manual techniques then are used to remove all of the remaining objectionable defects.

A multiple-saw gang crosscut is used to make one to four pieces from each board. The spacing between saws depends on the lengths of blanks that are to be made. The outer saws are used to trim the ends of those best boards that contain one long length cutting. Medium-quality boards contain a cutting that is longer than half the board length but shorter than a long cutting. The outer saws and one inner saw are used to cut these boards to one medium piece and one short piece. The remaining are low-quality boards. The 6-foot ones are crosscut to three short pieces and the 8-foot ones to four short pieces.

Pieces from the gang crosscut saw are accepted if they contain at least a minimum-size cutting (1½ inches wide by shortest blank length to be made). Only one cutting is made from each piece. To speed processing and make the operator's decisions easier, we recommend cutting-width increments no smaller than ½ inch. We use five cutting widths: 1½, 2, 2½, 3, and 3½ inches. Each piece to be gang sawed is inspected to choose its better edge. Then the piece is placed in one of five pockets on the gang-rip table. The ¼-inch edge cut (better edge) and the width cut to remove defects are made at the same time. Pieces from the gang ripsaw have edges of glue-joint quality.

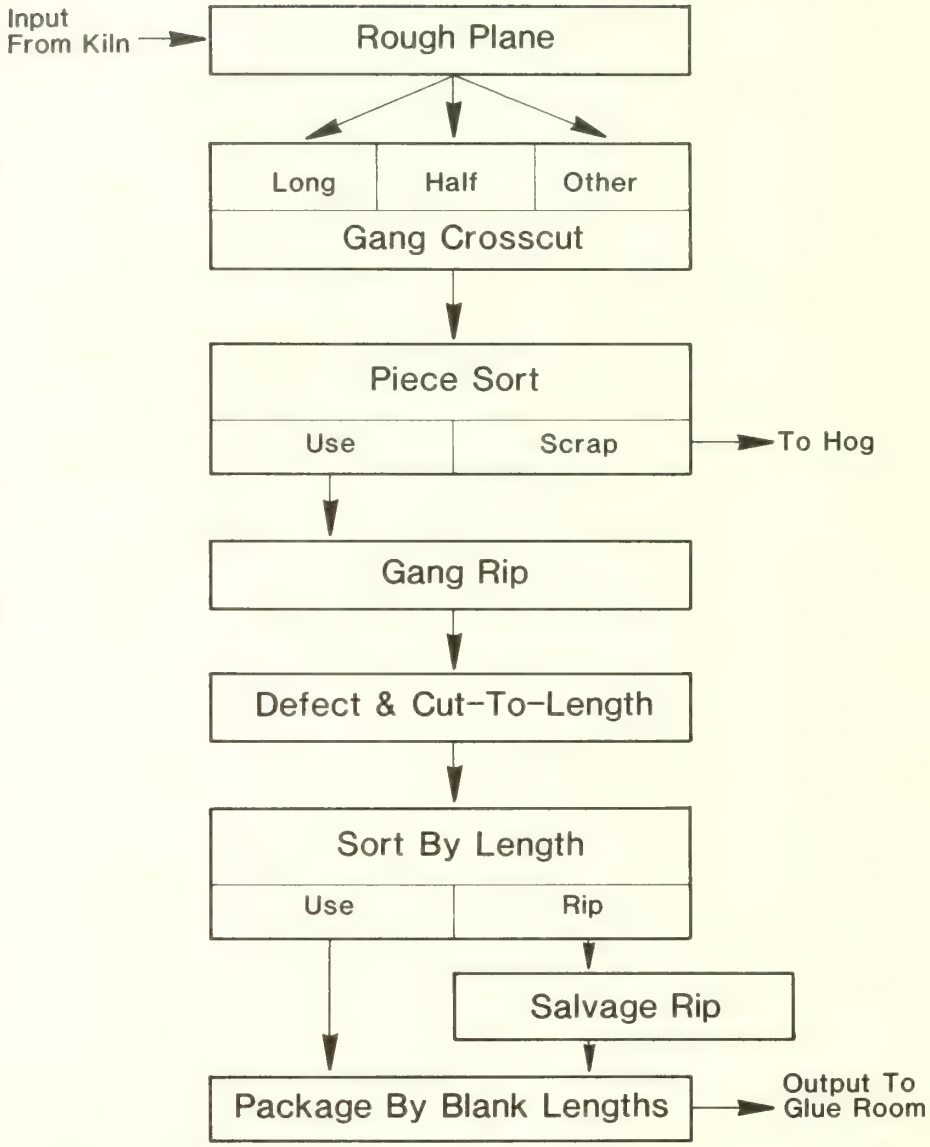

Figure 2.—Flowchart of System 6 rough mill.

Next, we bring pieces to specified size and quality with manual cut-up. After gang crosscutting and gang ripping, the cuttings are in no more than five lengths. There may still be some defects that need to be removed.

A manually controlled crosscut saw is used to remove end defects and cut pieces to blank lengths. A manually controlled glue-joint ripsaw is used for salvage ripcuts when required.

Gang-Crosscut Lengths

In System 6 all boards are used to make blanks. Most of these short (6 or 8 feet long), narrow (3¼ or 4 inches) boards are of poor quality. We have an automated method, gang crosscutting followed by gang ripping, to remove the majority of defects from the boards (Reynolds and Gatchell 1982).

The gang-crosscut saw is the heart of the System 6 rough mill (Figs. 3–4). This saw has four blades to be used to crosscut a 6-foot board and five blades to be used to crosscut an 8-foot board. The spacing between the saws and the position of saws for cutting (up to miss, down to cut) determine the lengths of pieces made when the board is crosscut. All crosscuts on a board are made in one pass through the machine.

The spacings between the sawblades, the GCL's, are chosen to obtain pieces in the most needed lengths. The spacings between the saws are set at the beginning of a run and are not changed during a run. When the two outside saws are down (in a cutting position) and the other saws are up, one long piece is made from each board. When a third saw is lowered, each board is cut into two pieces. When all of the saws are lowered, each board is cut into three pieces (6-foot boards) or to four pieces (8-foot boards).

Because requirements for quantities of blanks per length change according to market demands, many different sets of saw spacings are needed. I show how the saw spacings and saw positions are derived by using an example of gang-crosscut lengths for clear-quality, 26-inch-wide, 4/4-inch-thick blanks.

In the example, blanks longer than 72 inches are not needed so we use 6-foot boards. Blanks 72, 45, 25, and 21 inches long are in the greatest demand. We cut for these lengths on the gang-crosscut saw. The other blanks—60, 50, 38, 33, 29, 18, and 15 inches long—(see tabulation on page 2) are obtained at the cut-to-length saw when defects are trimmed off.

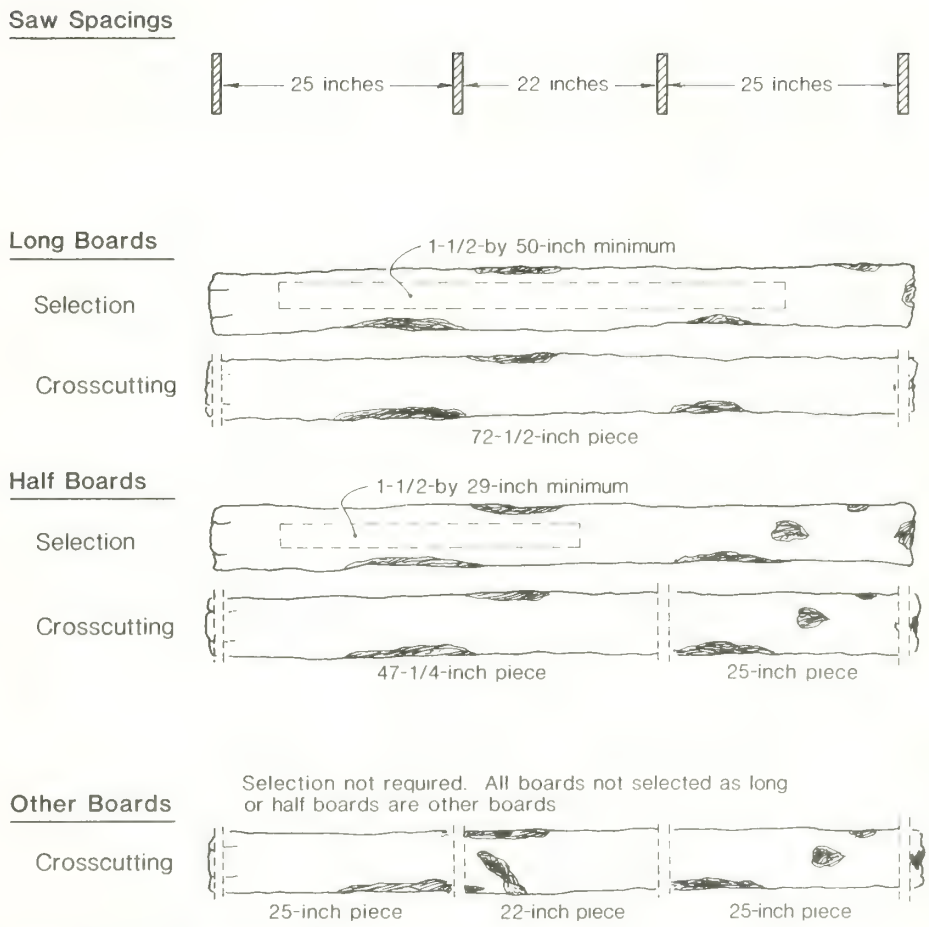

Figure 3.—Gang crosscutting (pictured is GCL 6A1 on 4-inch by 6-foot boards).

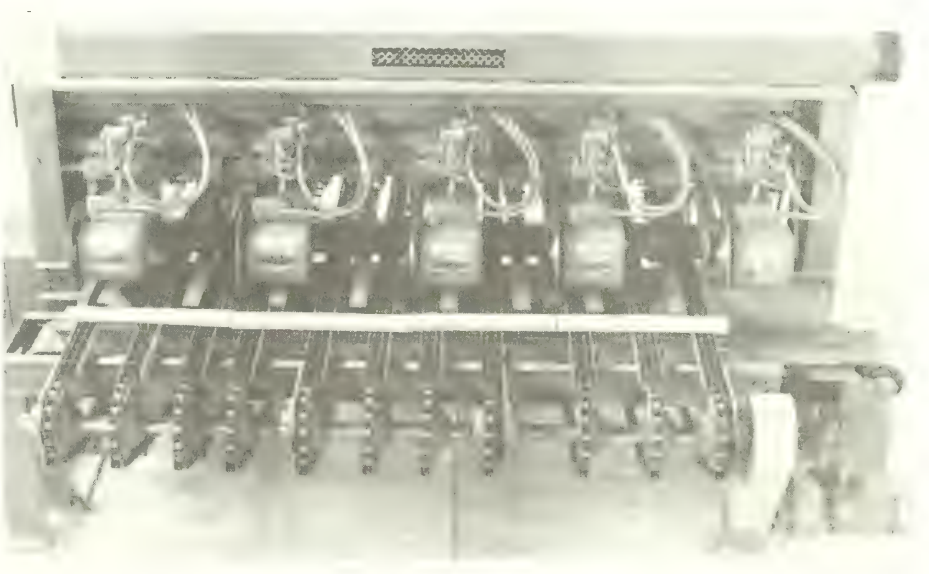

Figure 4.—System 6 gang-crosscut saw (outfeed side).

The first saw, on the right hand side facing the infeed side of the machine, is never moved (Fig. 3). The second saw is placed 25 inches from the first, the third 22 inches from the second, the fourth 25 inches from the third. The fifth saw is not used. With saws 1 and 4 down and 2 and 3 up, the 6-foot boards are crosscut to one full length piece. With saws 1, 2, and 4 down, the boards are crosscut to one 25-inch piece and one 47¼-inch piece. One-quarter-inch kerf sawblades are used. With all saws down, two 25-inch pieces and one 22-inch piece are made.

Pieces leaving the gang-crosscut saw are ripped and crosscut to remove defects. The 72½-inch pieces can be made to 72-inch and shorter lengths. The 47¼-inch pieces can be made to 45-inch and shorter lengths. The 22-inch pieces can be made to 21-inch and shorter pieces. In all cases, the longest possible length clear pieces are made.

Four examples of gang-crosscut length were derived for each of the 10 rough-mill operating blank quality/width/thickness combinations. Two examples are for 6-foot boards and two are for 8-foot boards. These examples are shown in Appendix I.

Knowing which blanks are to be made in what quantities and having the gang-crosscut saw spacings set, we can begin operating the rough mill.

Rough-Mill Operations

With the gang-crosscut saw set to cut boards into the desired piece lengths, the rough mill is ready for operation (Fig. 2). The machine operators take their instructions from the appropriate operating specification (A through J) in Appendix I. For purposes of explanation, I describe the rough-mill operations necessary to make clear-two-face (C2F) quality, 26-inch, 4/4 blanks in the 12 standard lengths (Appendix I, Operating Combination A). Six-foot-long boards are used. The gang-crosscut saw is set according to GCL1 for 6-foot boards (6A1) as in the previous section.

Packages of 6-foot boards are brought from the dry kiln to the rough mill. These 4/4 boards are fed into the rough planer where they are hit-and-miss planed on both sides to 1.000 inch. The boards then go to the gang-crosscut saw one at a time.

Each board is examined to determine if a long- or a medium-length cutting can be obtained. The operating specifications give the length of cutting required. In the C2F example, a board that will yield a 1½- by 50-inch clear cutting or larger is designated a "long" board. If a 1½- by 29-inch cutting or larger cutting can be obtained (but not a 1½- by 50-inch cutting), the board is given the "half" designation. All other boards not meeting the long and half designations are considered "other" boards.

The long boards are end trimmed only, the half boards are made to two pieces, and the other boards are made to three pieces (6-foot boards) or four pieces (8-foot boards). In the example, the long boards are end trimmed with saws 1 and 4 to one piece 72½ inches long (Fig. 3). The half boards are cut to one 47¼-inch and to one 25-inch piece with saws 1, 2, and 4. The other boards are cut to three pieces, 25, 22, and 25 inches long, with saws 1, 2, 3, and 4.

The gang-crosscut saw can be used in two ways. When the saw is equipped with an electronic memory, each board can be crosscut individually. As a board is put onto the infeed chains, buttons controlling the saws (up to miss, down to cut) are pushed. The memory notes which saws should be up and which should be down so that they are controlled correctly as the board passes through the saw area.

When an electronic memory is not available, a sorting technique is used. The saws are set (up to miss, down to cut) for the other boards. As these boards are identified, they are fed through the gang-crosscut saw. In the example, saws 1, 2, 3, and 4 would be down and the other boards would be cut to a 25-, a 22-, and a 25-inch piece. The long boards would be set aside in one pile and the half boards in another. When it is convenient, board planing (Fig. 2) would be stopped. The saws would be changed to cut the half boards. In the example, saws 1, 2, and 4 would be down. Following the crosscutting of the half board, the long boards would be trimmed. In the example, saws 1 and 4 would be down. After all of the long boards have been sent through the gang-crosscut saw, the planer is started and the cycle is repeated.

Pieces leaving the gang-crosscut saw are sorted so that only those with a clear area of 1½ by 15 inches are sent on to the gang ripsaw.

The operator of the gang ripsaw examines each piece to determine the better edge and determines how wide a clear piece can be ripped from that edge. He then puts the piece into the appropriate infeed pocket with the better edge against the fence. Since there are only five infeed pockets corresponding to 1½-, 2-, 2½-, 3-, or 3½-inch ripping widths, the operator soon becomes proficient in recognizing the correct ripping width. The operator always should be optimistic. We have found that the blank yield is best when 25 percent of the pieces must be salvage ripped to remove edge defects missed at the gang ripsaw.

Pieces leaving the gang ripsaw go to the defecting saws. In the example, the 72½, 47¼, or 22-inch pieces are trimmed to 72, 45, and 21 inches, respectively. Pieces with end defects are trimmed to the longest possible standard length. In this example, all 11 lengths—72, 60, 50, 45, 38, 33, 29, 25, 21, 18, and 15—are used. Pieces with edge defects are sent to the sal-

vage ripsaw. We always maximize for length as a 1½- by 60-inch piece (90 square inches) is more valuable than a 2- by 45-inch piece (also 90 square inches). Only one trimmed piece is made from each piece entering the defecting step. Multiple pieces may increase total yield but fewer long pieces would be made.

Pieces leave the defecting step and go to the sort-by-length step. The clear pieces are sorted by length regardless of width. Pieces with edge defects are sent to the salvage ripsaw. At the salvage ripsaw pieces are made 1½, 2, 2½, or 3 inches wide while the edge defects are removed. Pieces 1½ inches wide with edge defects are scrapped.

This concludes the rough mill processing. The rough kiln-dried boards enter the rough mill where they are cut to standard-size pieces (free of objectionable defects) ready for edge gluing to blank width.

The System 6 rough mill can be operated in a manner similar to that of a conventional rough mill. A GCL is selected and the gang crosscut is set up. All standard blank lengths are set on the defecting saw stops. Production is as described and yield by length is monitored. When enough pieces have been made in a given length, that length is deleted. When all blank requirements are met, the run is stopped. An improvement in this System 6 technique would be to switch to a different GCL, in the same operating combination series, when the most needed length requirements are satisfied.

A better manner for controlling System 6 rough mill production is available. The yields of blanks per GCL must be known before production. These data can be obtained by test or by previous experience with the single GCL processing control technique. The yield data per GCL together with the blank requirements per length are used as input data to the LP (linear programing) program S60PT (Appendix II).

The LP output shows the minimum quantity of boards to be processed by each GCL to obtain the required blanks. The only rough-mill change needed when changing GCL's is in the spacings of the gang-crosscut saw. The greatest advantage in operating the rough mill in this optimal GCL combination mode is that the mill runs without interruption. Production of pieces by length is not monitored and there is no deletion of piece lengths at the defecting saw. Production stops when the specified quantities of boards have been used.

S60PT shows the number of longer blanks in excess of requirements. The computer output shows how the excess longer blanks are to be crosscut to shorter blanks to meet requirements. The optimal yield is based on the total required blank production after crosscutting is done.

In comparing the use of the single GCL processing control technique with the combination of GCL techniques, Reynolds and Araman (1983) found that combinations of GCL's gave 3.0 to 12.5 percent better yields of required blanks than a single GCL.

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Appendix I

Operating Combination A

Clear (C1F and C2F) quality for 26-inch-wide, 4/4- and 5/4-inch-thick blanks
Standard lengths: 15, 18, 21, 25, 29, 33, 38, 45, 50, 60, 75, 100 inches

Rough plane:
4/4 boards 1.000 inch 5/4 boards 1.250 inches
hit-and-miss 2 sides

Gang crosscut:
GCL1 for 6-foot boards (6A1) full length, 45-, 25-, 21-inch blanks needed
Saw spacings (right to left):
1-2 25 inch, 2-3 22 inch, 3-4 25 inch, 5 not used
"Long" boards:
1½- by 50-inch minimum clear-quality area
Saws 1 and 4 down, 2 and 3 up; one 72½-inch piece
"Half" boards:
1½- by 29-inch minimum clear-quality area on right end
Saws 1, 2, and 4 down and 3 up; one 47¼- and one 25-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 4 down; two 25-inch pieces and one 22-inch piece
GCL2 for 6-foot boards (6A2) full length, 38-, 33-, 21-, 18-inch blanks needed
Saw spacings (right to left):
1-2 33 inch, 2-3 18 inch, 3-4 21 inch, 4 not used
"Long" boards:
1½- by 45-inch minimum clear-quality area
Saws 1 and 4 down, 2 and 3 up; 72½-inch piece
"Half" boards:
1½- by 29-inch minimum clear-quality area on right end
Saws 1, 2, and 4 down, 3 up; one 39¼ and one 33-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 4 down; one 33-, one 21-, and one 18-inch piece
GCL1 for 8-foot boards (8A1) full length, 60-, 38-, 33-, 25-inch blanks needed
Saw spacings (right to left):
1-2 33 inch, 2-3 25 inch, 3-5 38 inch, 4 not used
"Long" boards:
1½- by 75-inch minimum clear-quality area
Saws 1 and 5 down, 2 and 3 up; one 96½-inch piece
"Half" boards:
1½- by 45-inch minimum clear-quality area on right end
Saws 1, 2, and 5 down, 3 up; one 63½- and one 33-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 5 down; one 38-, one 33-, and one 25-inch piece
GCL2 for 8-foot boards (8A2) full length, 50-, 45-, 25-, 21-inch blanks needed
Saw spacings (right to left):
1-2 25 inch, 2-3 21 inch, 3-4 25 inch, 4-5 25 inch
"Long" boards:
1½- by 60-inch minimum clear-quality area
Saws 1 and 5 down, 2, 3, and 4 up; one 96¾-inch piece
"Half" boards:
1½- by 29-inch minimum clear-quality area on either end
Saws 1, 3, and 5 down, 2 and 4 up; one 46½- and one 50½-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, 4, and 5 down; three 25-inch pieces and one 21-inch piece

Piece sort:
Use any piece with a 1½- by 15-inch clear-quality area

Gang rip:
Rip to 1½-, 2-, 2½-, 3-, or 3½-inch width to remove edge defects to obtain clear-quality pieces

Defect and cut-to-length:
For 6-foot boards, set length stops at 15, 18, 21, 25, 29, 33, 38, 45, 50, 60, and 72 inches
For 8-foot boards, set length stops at 15, 18, 21, 25, 29, 33, 38, 45, 50, 60, 75, and 96 inches
Trim end defects to obtain clear-quality pieces while cutting to these standard lengths. Maximize length yield.

Sort by length:
Sort to piece lengths, no sorting by width. Pieces with edge defects are sent to the salvage ripsaw.

Salvage ripsaw:
Pieces with edge defects are ripped to make clear-quality pieces 1½, 2, 2½, or 3 inches wide.

Operating Combination B

Frame quality for 20-inch-wide, 4/4-inch-thick blanks
Standard lengths: 13, 17, 19, 22, 24, 27, 29, 33, 44, 54, 70, 80, 100 inches

Rough plane:
4/4 boards 1.000 inch hit-and-miss 2 sides

Gang crosscut:
GCL1 for 6-foot boards (6B1) full length, 44- and 24-inch blanks needed
Saw spacings (right to left):
1-2 24 inch, 2-3 24 inch, 3-4 24 inch, 5 not used
"Long" boards:
1½- by 54-inch minimum frame-quality area
Saws 1 and 4 down, 2 and 3 up; one 72½-inch piece
"Half" boards:
1½- by 27-inch minimum frame-quality area on right end
Saws 1, 2, and 4 down and 3 up; one 48¼- and one 24-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 4 down; three 24-inch pieces
GCL2 for 6-foot boards (6B2) full length, 33-, 22-, and 13-inch blanks needed
Saw spacings (right to left):
1-2 13 inch, 2-3 23 inch, 3-4 36 inch, 5 not used
"Long" boards:
1½- by 44-inch minimum frame-quality area
Saws 1 and 5 down and 2 and 3 up; one 72½-inch piece
"Half" boards:
1½- by 24-inch minimum frame-quality area on right end
Saws 1, 3, and 4 down and 2 up; one 36¼- and one 36-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 4 down; one 36-, one 23-, and one 13-inch piece

GCL1 for 8-foot boards (8B1) full length, 54-, 33-, and 29-inch blanks needed
Saw spacings (right to left):
1-2 30 inch, 2-3 33 inch, 3-5 33 inch, 4 not used
"Long" boards:
1½- by 70-inch minimum frame-quality area
Saws 1 and 4 down, 2 and 3 up; one 96½-inch piece
"Half" boards:
1½- by 27-inch minimum frame-quality area on right end
Saws 1, 3, and 5 down and 2 up; one 33¼- and one 33-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 5 down; two 33-inch pieces and one 30-inch piece
GCL2 for 8-foot boards (8B2) full length, 44-, and 24-inch blanks needed
Saw spacings (right to left):
1-2 24 inch, 2-3 24 inch, 3-4 24 inch, 4-5 24 inch
"Long" boards:
1½- by 54-inch minimum frame-quality area
Saws 1 and 5 down and 2, 3, and 4 up; one 96¾-inch piece
"Half" boards:
1½- by 27-inch minimum frame-quality area on right end
Saws 1, 3, and 5 down, 2 and 4 up; two 48¼-inch pieces
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, 4, and 5 down; four 24-inch pieces

Piece sort:
Use any piece with a 1½- by 13-inch frame-quality area

Gang rip:
Rip to 1½-, 2-, 2½-, 3-, or 3½-inch width to remove edge defects to obtain frame-quality pieces

Defect and cut-to-length:
For 6-foot boards, set length stops at 13, 17, 19, 22, 24, 27, 29, 33, 44, 54, and 72 inches
For 8-foot boards, set length stops at 13, 17, 19, 22, 24, 27, 29, 33, 44, 54, 70, 80, and 96 inches
Trim end defects to obtain frame-quality pieces while cutting at these standard lengths. Maximize length yield.

Sort by length:
Sort to piece lengths, no sorting by width. Pieces with edge defects are sent to the salvage ripsaw.

Salvage ripsaw:
Pieces with edge defects are ripped to make frame-quality pieces 1½, 2, 2½, or 3 inches wide.

Operating Combination C

Clear (C1F and C2F) quality for 26-inch-wide, 6/4- and 8/4-inch-thick blanks
Standard lengths: 15, 18, 21, 25, 28, 32, 35, 40, 45, 50, 60, 70, 90 inches

Rough plane:
6/4 boards 1.500 inches 8/4 boards 2.000 inches hit-and-miss 2 sides

Gang crosscut:
GCL1 for 6-foot boards (6C1) full length, 45-, 25-, and 21-inch blanks needed
Saw spacings (right to left):
1-2 25 inch, 2-3 22 inch, 3-4 25 inch, 5 not used
"Long" boards:
1½- by 50-inch minimum clear-quality area
Saws 1 and 4 down and 2 and 3 up; one 72½-inch piece
"Half" boards:
1½- by 35-inch minimum clear-quality area on right end
Saws 1, 2, and 4 down and 3 up; one 47¼- and one 25-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 4 down; two 25-inch pieces and one 22-inch piece
GCL2 for 6-foot boards (6C2) full length, 40-, 32-, 21-, and 18-inch blanks needed
Saw spacings (right to left):
1-2 32 inch, 2-3 18 inch, 3-4 22 inch, 5 not used
"Long" boards:
1½- by 45-inch minimum clear-quality area
Saws 1 and 4 down and 2 and 3 up; one 72½-inch piece
"Half" boards:
1½- by 35-inch minimum clear-quality area on right end
Saws 1, 2, and 4 down and 3 up; one 40¼- and one 32-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 4 down; one 32-inch, one 22-inch, and one 18-inch piece
GCL1 for 8-foot boards (8C1) full length, 60- and 32-inch blanks needed
Saw spacings (right to left):
1-2 32 inch, 2-3 32 inch, 3-5 32 inch, 4 not used
"Long" boards:
1½- by 70-inch minimum clear-quality area
Saws 1 and 5 down and 2 and 3 up; one 96½-inch piece
"Half" boards:
1½- by 35-inch minimum clear-quality area on right end
Saws 1, 2, and 5 down and 3 up; one 64¼- and one 32-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 5 down; three 32-inch pieces
GCL2 for 8-foot boards (8C2) full length, 50-, 45-, 25-, and 21-inch blanks needed
Saw spacings (right to left):
1-2 25 inch, 2-3 21 inch, 3-4 25 inch, 4-5 25 inch
"Long" boards:
1½- by 60-inch minimum clear-quality area
Saws 1 and 5 down and 2, 3, and 4 up; one 96¾-inch piece
"Half" boards:
1½- by 29-inch minimum clear-quality area on right end
Saws 1, 3, and 5 down and 2 and 4 up; one 46¼- and one 50-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, 4, and 5 down; three 25-inch pieces and one 21-inch piece

Piece sort:
Use any piece with a 1½- by 15-inch clear-quality area

Gang rip:
Rip to 1½-, 2-, 2½-, 3-, or 3½-inch width to remove edge defects to obtain clear-quality pieces

Defect and cut-to-length:
For 6-foot boards, set length stops at 15, 18, 21, 25, 28, 32, 40, 45, 50, 60, and 72 inches
For 8-foot boards, set length stops at 15, 18, 21, 25, 28, 32, 40, 45, 50, 60, 70, and 90 inches
Trim end defects to obtain clear-quality pieces while cutting at these standard lengths. Maximize length yield.

Sort by length:
Sort to piece lengths, no sorting by width. Pieces with edge defects are sent to the salvage ripsaw.

Salvage ripsaw:
Pieces with edge defects are ripped to make clear-quality pieces 1½, 2, 2½, or 3 inches wide.

Operating Combination D

Interior quality for 20-inch-wide, 4/4-inch-thick blanks
Standard lengths: 15, 18, 21, 25, 29, 34, 40, 50, 60, 70, and 95 inches

Rough plane:
4/4 boards 1.000 inch hit-and-miss 2 sides

Gang crosscut:
GCL1 for 6-foot boards (6D1) full length, 50-, 25-, and 21-inch blanks needed
Saw spacings (right to left):
1-2 25 inch, 2-3 25 inch, 3-4 22 inch, 5 not used
"Long" boards:
1½- by 60-inch minimum interior-quality area
Saws 1 and 4 down and 2 and 3 up; one 72½-inch piece
"Half" boards:
1½- by 29-inch minimum interior-quality area on right end
Saws 1, 3, and 4 down and 2 up; one 50¼- and one 22-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 4 down; two 25-inch pieces and one 22-inch piece
GCL2 for 6-foot boards (6D2) full length, 40-, 29-, 25-, and 18-inch blanks needed
Saw spacings (right to left):
1-2 29 inch, 2-3 18 inch, 3-4 25 inch, 5 not used
"Long" boards:
1½- by 50-inch minimum interior-quality area
Saws 1 and 4 down and 2 and 3 up; one 72½-inch piece
"Half" boards:
1½- by 34-inch minimum interior-quality area on right end
Saws 1, 2, and 4 down and 3 up; one 43¼- and one 29-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 4 down; one 29-, one 25-, and one 18-inch piece
GCL1 for 8-foot boards (8D1) full length, 60-, 34-, and 25-inch blanks needed
Saw spacings (right to left):
1-2 34 inch, 2-3 25 inch, 3-5 37 inch, 4 not used
"Long" boards:
1½- by 70-inch minimum interior-quality area
Saws 1 and 5 down and 2 and 3 up; one 96½-inch piece
"Half" boards:
1½- by 40-inch minimum interior-quality area on right end
Saws 1, 2, and 5 down and 3 up; one 62¼- and one 34-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 5 down; one 37-, one 34-, and one 25-inch piece
GCL2 for 8-foot boards (8D2) full length, 50-, 40-, 25-, and 21-inch blanks needed
Saw spacings (right to left):
1-2 25 inch, 2-3 21 inch, 3-4 25 inch, 4-5 25 inch
"Long" boards:
1½- by 60-inch minimum interior-quality area
Saws 1 and 5 down and 2, 3, and 4 up; one 96¾-inch piece
"Half" boards:
1½- by 29-inch minimum interior-quality area on right end
Saws 1, 3, and 5 down and 2 and 4 up; one 50¼- and one 46¼-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, 4, and 5 down; three 25-inch pieces and one 21-inch piece

Piece sort:
Use any piece with a 1½- by 15-inch interior-quality area

Gang rip:
Rip to 1½-, 2-, 2½-, 3-, or 3½-inch width to remove edge defects to obtain interior-quality pieces

Defect and cut-to-length:
For 6-foot boards, set length stops at 15, 18, 21, 25, 29, 34, 40, 50, 60, and 72 inches
For 8-foot boards, set length stops at 15, 18, 21, 25, 29, 34, 40, 50, 60, 70, and 95 inches
Trim end defects to obtain interior-quality pieces while cutting at these standard lengths. Maximize length yield.

Sort by length:
Sort to piece lengths, no sorting by widths. Pieces with edge defects are sent to the salvage ripsaw.

Salvage ripsaw:
Pieces with edge defects are ripped to make interior-quality pieces 1½, 2, 2½, or 3 inches wide.

Operating Combination E

Core quality for 26-inch-wide, 4/4-inch-thick blanks
Standard lengths: 15, 18, 21, 23, 26, 29, 34, 40, 50, 60, 70, 95 inches

Rough plane:
4/4 boards 1.000 inch hit-and-miss 2 sides

Gang crosscut:
GCL1 for 6-foot boards (6E1) full length, 50-, 26-, 23-, and 21-inch blanks needed
Saw spacings (right to left):
1-2 21 inch, 2-3 23 inch, 3-4 28 inch, 5 not used
"Long" boards:
1½- by 60-inch minimum core-quality area
Saws 1 and 4 down and 2 and 3 up; one 72½-inch piece
"Half" boards:
1½- by 29-inch minimum core-quality area on right end
Saws 1, 2, and 4 down and 3 up; one 51¼- and one 21-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 4 down; one 28-, one 23-, and one 21-inch piece
GCL2 for 6-foot boards (6E2) full length, 34- and 18-inch blanks needed
Saw spacings (right to left):
1-2 34 inch, 2-3 18 inch, 3-4 20 inch, 5 not used
"Long" boards:
1½- by 40-inch minimum core-quality area
Saws 1 and 4 down and 2 and 3 up; one 72½-inch piece
"Half" boards:
1½- by 34-inch minimum core-quality area on right end
Saws 1, 2, and 4 down and 3 up; one 38¼- and one 34-inch piece
"Other" boards:
All other boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 4 down; one 34-, one 20-, and one 18-inch piece
GCL1 for 8-foot boards (8E1) full length, 60-, 34-, and 26-inch blanks needed
Saw spacings (right to left):
1-2 34 inch, 2-3 26 inch, 3-5 36 inch, 4 not used
"Long" boards:
1½- by 70-inch minimum core-quality area
Saws 1 and 5 down and 2 and 3 up; one 96½-inch piece
"Half" boards:
1½- by 40-inch minimum core-quality area on right end
Saws 1, 2, and 5 down and 3 up; one 62¼- and one 34-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 5 down; one 36-, one 34-, and one 26-inch piece
GCL2 for 8-foot boards (8E2) full length, 50-, 40-, 26-, 23-, and 21-inch blanks needed
Saw spacings (right to left):
1-2 23 inch, 2-3 21 inch, 3-4 26 inch, 4-5 26 inch
"Long" boards:
1½- by 60-inch minimum core-quality area
Saws 1 and 5 down and 2, 3, and 4 up; one 96¾-inch piece
"Half" boards:
1½- by 29-inch minimum core-quality area on right end
Saws 1, 3, and 5 down and 2 and 4 up; one 52¼- and one 44¼-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, 4, and 5 down; two 26-inch pieces, one 23-, and one 21-inch piece

Piece sort:
Use any piece with a 1½- by 15-inch core-quality area

Gang rip:
Rip to 1½-, 2-, 2½-, 3-, or 3½-inch width to remove edge defects to obtain core-quality pieces

Defect and cut-to-length:
For 6-foot boards, set length stops at 15, 18, 21, 23, 26, 29, 34, 40, 50, 60, and 72 inches
For 8-foot boards, set length stops at 15, 18, 21, 23, 26, 29, 34, 40, 50, 60, 70, and 95 inches
Trim end defects to obtain core-quality pieces while cutting at these standard lengths. Maximize length yield.

Sort by length:
Sort to piece lengths, no sorting by widths. Pieces with edge defects are sent to the salvage ripsaw.

Salvage ripsaw:
Pieces with edge defects are ripped to make core-quality pieces 1½, 2, 2½, or 3 inches wide.

Operating Combination F

Frame quality for 20-inch-wide, 5/4-inch-thick blanks
Standard lengths: 15, 18, 20, 23, 25, 28, 33, 45, 55, 65, 80, 90, and 100 inches

Rough plane:
5/4 boards 1.250 inches hit-and-miss 2 sides

Gang crosscut:
GCL1 for 6-foot boards (6F1) full length, 45-, 25-, and 23-inch blanks needed
Saw spacings (right to left):
1-2 25 inch, 2-3 24 inch, 3-4 23 inch, 5 not used
"Long" boards:
1½- by 55-inch minimum frame-quality area
Saws 1 and 4 down and 2 and 3 up; one 72½-inch piece
"Half" boards:
1½- by 28-inch minimum frame-quality area on right end
Saws 1, 2, and 4 down and 3 up; one 47¼- and one 25-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 4 down; one 25-, one 24-, and one 23-inch piece
GCL2 for 6-foot boards (6F2) full length, 33-, 20-, and 18-inch blanks needed
Saw spacings (right to left):
1-2 33 inch, 2-3 18 inch, 3-4 21 inch, 5 not used
"Long" boards:
1½- by 45-inch minimum frame-quality area
Saws 1 and 4 down and 2 and 3 up; one 72½-inch piece
"Half" boards:
1½- by 33-inch minimum frame-quality area on right end
Saws 1, 2, and 4 down and 3 up; one 39¼- and one 33-inch piece
"Other" boards:
All other boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 4 down; one 33-, one 21-, and one 18-inch piece
GCL1 for 8-foot boards (8F1) full length, 65-, 33-, and 28-inch blanks needed
Saw spacings (right to left):
1-2 30 inch, 2-3 33 inch, 3-5 33 inch, 4 not used
"Long" boards:
1½- by 80-inch minimum frame-quality area
Saws 1 and 5 down and 2 and 3 up; one 96½-inch piece
"Half" boards:
1½- by 45-inch minimum frame-quality area on right end
Saws 1, 2, and 5 down and 3 up; one 66¼- and one 30-inch piece
"Other" boards:
All other boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 5 down; two 33-inch pieces and one 30-inch piece
GCL2 for 8-foot boards (8F2) full length, 45-, 25-, and 23-inch blanks needed
Saw spacings (right to left):
1-2 23 inch, 2-3 25 inch, 3-4 23 inch, 4-5 25 inch
"Long" boards:
1½- by 55-inch minimum frame-quality area
Saws 1 and 5 down and 2, 3, and 4 up; one 96¾-inch piece
"Half" boards:
1½- by 28-inch minimum frame-quality area on right end
Saws 1, 3, and 5 down and 2 and 4 up; two 48¼-inch pieces
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, 4, and 5 down; two 25- and two 23-inch pieces

Piece sort:
Use any piece with a 1½- by 15-inch frame-quality area

Gang rip:
Rip to 1½-, 2-, 2½-, 3-, or 3½-inch width to remove edge defects to obtain frame-quality pieces

Defect and cut-to-length:
For 6-foot boards, set length stops at 15, 18, 20, 23, 25, 28, 33, 45, 55, 65, and 72 inches
For 8-foot boards, set length stops at 15, 18, 20, 23, 25, 28, 33, 45, 55, 65, 80, 90, and 96 inches
Trim end defects to obtain frame-quality pieces while cutting to these standard lengths. Maximize length yield.

Sort by length:
Sort to piece lengths, no sorting by widths. Pieces with edge defects are sent to the salvage ripsaw.

Salvage ripsaw:
Pieces with edge defects are ripped to make frame-quality pieces 1½, 2, 2½, or 3 inches wide.

Operating Combination G

Clear (C1F and C2F) quality for 26-inch-wide, 5/8-inch-thick blanks
Standard lengths: 13, 15, 17, 18, 22, 26, 31, 36, and 42 inches

Rough plane:
5/8 boards 0.625 inch hit-and-miss 2 sides

Gang crosscut:
GCL1 for 6-foot boards (6G1): 42-, 26-, and 22-inch blanks needed
Saw spacings (right to left):
1-2 22 inch, 2-3 24 inch, 3-4 26 inch, 5 not used
No "long" boards needed
"Half" boards:
1½- by 31-inch minimum clear-quality area on right end
Saws 1, 2, and 5 down and 3 up; one 50¼- and one 22-inch piece
"Other" boards:
All boards not meeting "half" criteria
Saws 1, 2, 3, and 4 down; one 26-, one 24-, and one 22-inch piece
GCL2 for 6-foot boards (6G2): 36- and 18-inch blanks needed
Saw spacings (right to left):
1-2 18 inch, 2-3 18 inch, 3-4 18 inch, 4-5 18 inch
No "long" boards needed
"Half" boards:
1½- by 22-inch minimum clear-quality area on either end
Saws 1, 3, and 4 down and 2 and 5 up; two 36¼-inch pieces
"Other" boards:
All boards not meeting "half" criteria
Saws 1, 2, 3, 4, and 5 down; four 18-inch pieces
GCL1 for 8-foot boards (8G1): 31-inch blanks needed
Saw spacings (right to left):
1-2 31 inch, 2-3 31 inch, 3-5 34 inch, 4 not used
No "long" or "half" boards needed
"Other" boards:
All boards
Saws 1, 2, 3, and 5 down; one 34-inch piece and two 31-inch pieces
GCL2 for 8-foot boards (8G2): 42-, 26-, and 22-inch blanks needed
Saw spacings (right to left):
1-2 22 inch, 2-3 22 inch, 3-4 26 inch, 4-5 26 inch
No "long" boards needed
"Half" boards:
1½- by 31-inch minimum clear-quality area on right end
Saws 1, 3, 4, and 5 down and 2 up; one 44¼-inch piece and two 26-inch pieces
"Other" boards:
All boards not meeting the "half" criteria
Saws 1, 2, 3, 4, and 5 down; two 26- and two 22-inch pieces

Piece sort:
Use any piece with a 1½- by 13-inch clear-quality area

Gang rip:
Rip to 1½-, 2-, 2½-, 3-, or 3½-inch width to remove edge defects to obtain clear-quality pieces

Defect and cut-to-length:
For 6- and 8-foot boards, set length stops at 13, 15, 17, 18, 22, 26, 31, 36, and 42 inches
Trim end defects to obtain clear-quality pieces while cutting to these standard lengths. Maximize length yield.

Sort by length:
Sort to piece lengths, no sorting by widths. Pieces with edge defects are sent to the salvage ripsaw.

Salvage ripsaw:
Pieces with edge defects are ripped to make clear-quality pieces 1½, 2, 2½, or 3 inches wide.

Operating Combination H

Frame quality for 20-inch-wide, 8/4-inch-thick blanks
Standard lengths: 12, 16, 19, 21, 24, 28, 30, and 34 inches

Rough plane:
8/4 boards 2.000 inches hit-and-miss 2 sides

Gang crosscut:
GCL1 for 6-foot boards (6H1): 34-, 24-, and 12-inch blanks needed
Saw spacings (right to left):
1-2 24 inch, 2-3 24 inch, 3-4 24 inch, 5 not used
No "long" boards needed
"Half" boards:
1½- by 28-inch minimum frame-quality area on right end
Saws 1, 2, and 4 down and 3 up; one 48¼- and one 24-inch piece
"Other" boards:
All boards not meeting "half" criteria
Saws 1, 2, 3, and 4 down; three 24-inch pieces
GCL2 for 6-foot boards (6H2): 34-, 19-, and 16-inch blanks needed
Saw spacings (right to left):
1-2 16 inch, 2-3 20 inch, 3-4 16 inch, 4-5 20 inch
No "long" boards needed
"Half" boards:
1½- by 21-inch minimum frame-quality area on either end
Saws 1, 3, and 5 down and 2 and 4 up; two 36¼-inch pieces
"Other" boards:
All boards not meeting the "half" criteria
Saws 1, 2, 3, 4, and 5 down; two 20- and two 16-inch pieces
GCL1 for 8-foot boards (8H1): 34- and 28-inch blanks needed
Saw spacings (right to left):
1-2 28 inch, 2-3 34 inch, 3-5 34 inch, 4 not used
No "long" or "half" boards needed
"Other" boards:
All boards
Saws 1, 2, 3, and 5 down; two 34-inch pieces and one 28-inch piece
GCL2 for 8-foot boards (8H2): 24-inch blanks needed
Saw spacings (right to left):
1-2 24 inch, 2-3 24 inch, 3-4 24 inch, 4-5 24 inch
No "long" or "half" boards needed
"Other" boards:
All boards
Saws 1, 2, 3, 4, and 5 down; four 24-inch pieces

Piece sort:
Use any piece with a 1½- by 12-inch frame-quality area

Gang rip:
Rip to 1½-, 2-, 2½-, 3-, or 3½-inch width to remove edge defects to obtain frame-quality pieces

Defect and cut-to-length:
For 6- and 8-foot boards, set length stops at 12, 16, 19, 21, 24, 28, 30, and 34 inches
Trim end defects to obtain frame-quality pieces while cutting to these standard lengths. Maximize length yields.

Sort by length:
Sort to piece lengths, no sorting by widths. Pieces with edge defects are sent to the salvage ripsaw.

Salvage ripsaw:
Pieces with edge defects are ripped to make frame-quality pieces 1½, 2, 2½, or 3 inches wide.

Operating Combination I

Frame quality for 20-inch-wide, 6/4-inch-thick blanks
Standard lengths: 14, 18, 21, 24, 28, 31, 34, and 40 inches

Rough plane:
6/4 boards 1.2500 inches hit-and-miss 2 sides

Gang crosscut:
GCL1 for 6-foot boards (6I1): 40-, 28-, and 21-inch blanks needed
Saw spacings (right to left):
1–2 30 inch, 2–3 21 inch, 3–4 21 inch, 5 not used
No "long" boards needed
"Half" boards:
1½- by 31-inch minimum frame-quality area on right end
Saws 1, 2, and 4 down and 3 up; one 42¼- and one 30-inch piece
"Other" boards:
All boards not meeting the "half" criteria
Saws 1, 2, 3, and 4 down; one 30-inch piece and two 21-inch pieces
GCL2 for 6-foot boards (6I2): 40-, 31-, 21-, and 18-inch blanks needed
Saw spacings (right to left):
1–2 31 inch, 2–3 21 inch, 3–4 20 inch, 5 not used
No "long" boards needed
"Half" boards:
1½- by 34-inch minimum frame-quality area on right end
Saws 1, 2, and 4 down and 3 up; one 41¼- and one 31-inch piece
"Other" boards:
All boards not meeting the "half" criteria
Saws 1, 2, 3, and 4 down; one 31-, one 21-, and one 20-inch piece
GCL1 for 8-foot boards (8I1): 34- and 31-inch blanks needed
Saw spacings (right to left):
1–2 31 inch, 2–3 31 inch, 3–5 34 inch, 4 not used
No "long" or "half" boards needed
"Other" boards:
All boards
Saws 1, 2, 3, and 5 down; one 34-inch piece and two 31-inch pieces
GCL2 for 8-foot boards (8I2): 40-, 28-, 24-, and 21-inch blanks needed
Saw spacings (right to left):
1–2 24 inch, 2–3 30 inch, 3–4 21 inch, 3–5 21 inch
No "long" boards needed
"Half" boards:
1½- by 31-inch minimum frame-quality area on right end
Saws 1, 2, 3, and 5 down and 4 up; one 42¼-, one 30-, and one 24-inch piece
"Other" boards:
All boards not meeting the "half" criteria
Saws 1, 2, 3, 4, and 5 down; one 30- and one 24-inch piece, and two 21-inch pieces

Piece sort:
Use any piece with a 1½- by 14-inch frame-quality area

Gang rip:
Rip to 1½-, 2-, 2½-, 3-, or 3½-inch width to remove edge defects to obtain frame-quality pieces

Defect and cut-to-length:
For 6- and 8-foot boards, set length stops at 14, 18, 21, 24, 28, 31, 34, and 40 inches
Trim end defects to obtain frame-quality pieces while cutting to these standard lengths. Maximize length yields.

Sort by length:
Sort to piece lengths, no sorting by widths. Pieces with edge defects are sent to the salvage ripsaw.

Salvage ripsaw:
Pieces with edge defects are ripped to make frame-quality pieces 1½, 2, 2½, or 3 inches wide.

Operating Combination J

Clear (C1F and C2F) quality for 26-inch-wide, 3/4-inch-thick blanks
Standard lengths: 14, 17, 19, 22, 25, 29, 31, 35, 41, 47, 58, and 86 inches

Rough plane:
3/4 boards 0.75 inch hit-and-miss 2 sides

Gang crosscut:
GCL1 for 6-foot boards (6J1): full length, 47-, 25-, and 22-inch blanks needed
Saw spacings (right to left):
1-2 22 inch, 2-3 25 inch, 3-4 25 inch, 5 not used
"Long" boards:
1½- by 58-inch minimum clear-quality area
Saws 1 and 4 down and 2 and 3 up; one 72½-inch piece
"Half" boards:
1½- by 29-inch minimum clear-quality area on right end
Saws 1, 2, and 4 down and 3 up; one 50¼- and one 27-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 4 down; two 25-inch pieces and one 22-inch piece
GCL2 for 6-foot boards (6J2): full length, 35-, 22-, and 14-inch blanks needed
Saw spacings (right to left):
1-2 35 inch, 2-3 15 inch, 3-4 22 inch, 5 not used
"Long" boards:
1½- by 41-inch minimum clear-quality area
Saws 1 and 4 down and 2 and 3 up; one 72½-inch piece
"Half" boards:
1½- by 35-inch minimum clear-quality area on right end
Saws 1, 2, and 4 down and 3 up; one 37¼- and one 35-inch piece
"Other" boards:
All boards not meeting the "long" or "half" criteria
Saws 1, 2, 3, and 4 down; one 35-, one 22-, and one 15-inch piece
GCL1 for 8-foot boards (8J1): 86-, 58-, 35-, 31-, and 29-inch blanks needed
Saw spacings (right to left):
1-2 36 inch, 2-3 29 inch, 3-5 31 inch, 4 not used
"Long" boards:
1½- by 86-inch minimum clear-quality area
Saws 1 and 5 down and 2 and 3 up; one 96½-inch piece
"Half" boards:
1½- by 41-inch minimum clear-quality area on right end
Saws 1, 2, and 5 down and 3 up; one 60¼- and one 36-inch piece
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, and 5 down; one 36-, one 31-, and one 29-inch piece
GCL2 for 8-foot boards (8J2): 86-, 47-, 25-, and 22-inch blanks needed
Saw spacings (right to left):
1-2 23 inch, 2-3 25 inch, 3-4 23 inch, 4-5 25 inch
"Long" boards:
1½- by 58-inch minimum clear-quality area
Saws 1 and 5 down and 2, 3, and 4 up; one 96¾-inch piece
"Half" boards:
1½- by 29-inch minimum clear-quality area on right end
Saws 1, 3, and 5 down and 2 and 4 up; two 48¼-inch pieces
"Other" boards:
All boards not meeting "long" or "half" criteria
Saws 1, 2, 3, 4, and 5 down; two 25- and two 23-inch pieces

Piece sort:
Use any piece with a 1½- by 14-inch clear-quality area

Gang rip:
Rip to 1½-, 2-, 2½-, 3-, or 3½-inch width to remove edge defects to obtain clear-quality pieces

Defect and cut-to-length:
For 6-foot boards, set length stops at 14, 17, 19, 22, 25, 29, 31, 35, 41, 58, and 72 inches
For 8-foot boards, set length stops at 14, 17, 19, 22, 25, 29, 31, 35, 41, 58, and 86 inches
Trim end defects to obtain clear-quality pieces while cutting to these standard lengths. Maximize length yield.

Sort by length:
Sort to piece lengths, no sorting by widths. Pieces with edge defects are sent to the salvage ripsaw.

Salvage ripsaw:
Pieces with edge defects are ripped to make clear-quality pieces 1½, 2, 2½, or 3 inches wide.

Appendix II

S60PT: Linear Programing Optimization

This version of S60PT is programed using MPS-III written by Ketron, Inc., 1700 N. Moore Street, Arlington, VA 22209. The program will run on computers that have the MPS-III compiler. This LP use is very limited in function as we only want to know the least board quantity needed to obtain the required blanks.

Three sets of data are required: the yield of blanks in each length by each GCL for the given board quality, the quantity of blanks required in each length for the given blank quality, and the yields when long blanks are trimmed to shorter blanks. All board inputs, all yield values by operating method, and all blank outputs are on a surface square-foot basis.

GCL Data Set

Each operating method data set is specific to:

- The board-quality level from a specific site or a specified sample.
- A single species from that site or sample.
- The GCL used to convert the rough dry boards to blanks.
- The lengths of blanks made by that GCL.

In System 6 research work, each GCL data set is determined by actual test. Dried boards are made to blanks of specified lengths by the operating method being tested. The yield values in each blank length make up the data set. Values are given in terms of square feet of blanks per square foot of boards used.

Blanks Requirement Data Set

Araman et al. (1982) studied the solid wood parts needs of the furniture and kitchen cabinet industries. The recommended sizes and qualities for standard-size hardwood blanks were made from these study data. When a furniture or cabinet company buys or makes blanks in these sizes and qualities, there should be no more than 10 percent end trim loss in making rough-dimension parts from blanks.

The quantity of blanks per length, thickness, and quality must be specified. The blanks requirement data set is given in terms of square feet per blank length for a total of 1,000 square feet of blanks. Only one blank quality and blank thickness may be used per data set.

Trim Method Data Sets

System 6 operating methods are not designed to make all blank lengths, nor could enough operating methods be developed that would produce all of the blanks needed in each length. Instead, the operating methods are designed to obtain as many long blanks as possible. The long blanks that are extras then can be trimmed back to make shorter blanks to fulfill requirements.

All possible combinations for making shorter blanks from longer blanks must be specified to allow the LP program to make the optimal choice. Trim-method data are given in the form of square feet of shorter blanks that can be made from a longer blank. As an example, 1 square foot of 70-inch-long blank can be trimmed to 0.771 square foot of 54-inch blank (54/70 = 0.771) plus 0.186 square foot of 13-inch blank (13/70 = 0.186). Kerf loss of the trimsaw is ignored and is considered part of the waste. To be consistent, therefore, a square foot of 44-inch blank can be trimmed to a square foot of 22-inch blank [(22 + 22)/44 = 1.0].

The trim-method data set must correspond to all the long blanks made and all the shorter lengths required. Additional trim-method data will lead to error with the program assuming some blanks are available that are not.

Card Deck

The card deck layout is shown in Figure 5.

JCL cards: The seven job control cards are given for the job and account numbers used by the author. All data starts in column 1.

```
//B0945HWR JOB 00510,REYNOLDS
/*ROUTE PRINT MVS1.RMT04
/*LONGKEY GATCHEL
/*PRIORITY PRIORITY
/*JOBPARM LINES=3
//STEP1 EXEC LP
//LP.SYSIN DD *
```

Program cards: The 15 program cards are given for the LP options used by the author. All data starts in column 10.

```
PROGRAM
INITIALZ
TITLE ('ANY TITLE UP TO COL-
  UMN 79')
```

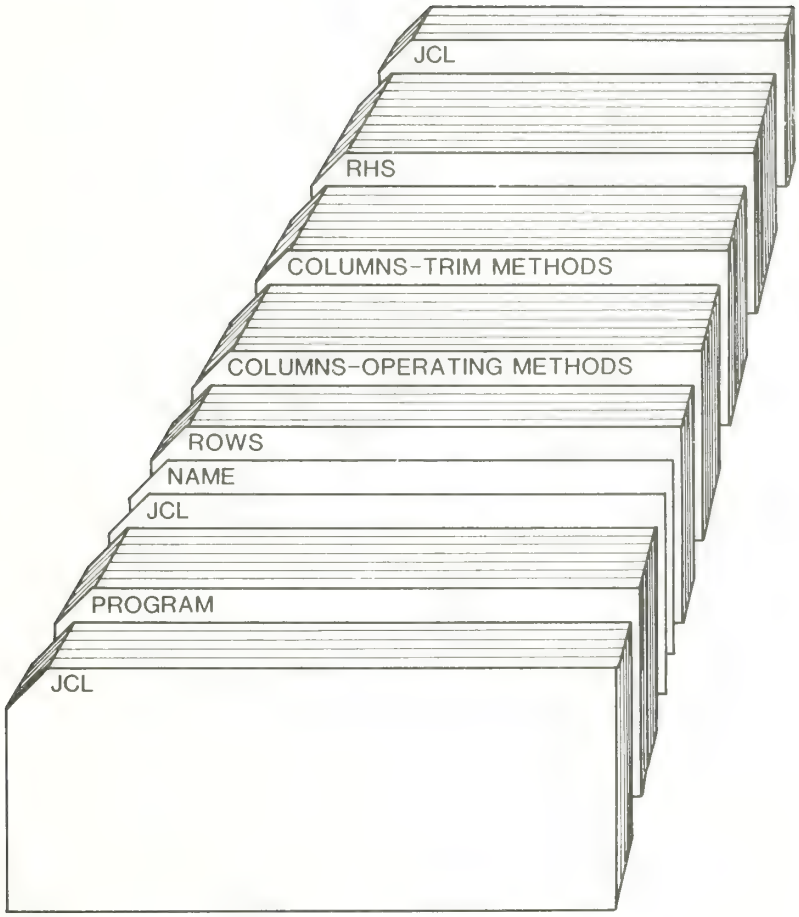

Figure 5.—Card deck layout.

MOVE (XDATA, 'NAME') Name can be eight characters and/or numbers. No embedded blanks.
MOVE (XPBNAME, 'PBFILE')
CONVERT ('SUMMARY')
BCDOUT
MOVE (XOBJ, 'MINBOARD') The objective function is always named MINBOARD
MOVE (XRHS, 'REQD')
SETUP
PICTURE
VARIFORM
SOLUTION
EXIT
PEND

JCL cards: Two cards are used to introduce the data sections. All data starts in column 1.

```
/*
//GO.SYSIN DD *
```

Name cards: Name card and any comment cards.

NAME (start in column 1) Name—start in column 15. Name can be eight characters and/or numbers. No embedded blanks.

*(Column 1) comment cards any character or number and period. These comments will not appear in the program listing or output.

Row cards: The first card is "ROWS" and each additional card gives one row, name, and the kind of row parameter on the RHS.

L = less than or equal to (for salvage blank lengths less than 20 inches).

G = greater than or equal to (for all required blank lengths except the salvage lengths).

N = objective function.

Blank length is used as the row name for all except the objective function, which is named MINBOARD. Example: BL/70 is name of the blank length 70-inch row.

Rows (start in column 1)

Parameter (N.L, or G in column 3). Name—start in column 5. Name can be eight characters and/or numbers and period. No embedded blanks.

There must be a row name for each blank length to be considered even though that length may not be made by any of the operating methods and can only be made by a trim method.

Column cards: OPERATING METHODS—The first card is "COLUMNS." Each additional columns card gives an operating method name in the LP matrix. In addition, two element values of the matrix data, not zero, are given by row, name, and value. All names and values are left justified. Zero matrix values do not have to be entered.

COLUMNS (start in column 1).

Operating Method Name	*Row Name*	*Element Value*	*Row Name*	*Element Value*
Operating method name	: card columns 5-12			
Row name	: card columns 15-22			
Matrix value	: card columns 25-36			
Row name	: card columns 40-47			
Matrix value	: card columns 50-61			

Column cards: TRIM METHODS. Each additional columns card gives a trim-method name in the LP matrix. The trim-method name is given with the length of the long blanks to be trimmed and the longest shorter length blank to be made. Example: TM70.54 is the trim method that takes 70-inch-long blanks and trims them to a 54-inch-long blank plus a 13-inch-long blank. The matrix element giving the long blank length is always −1.0 to show that this is a blank in excess of requirements. All names and values are left justified.

Trim Method Name	*Row Name*	*Element Value*	*Row Name*	*Element Value*
Trim method name	: card columns 5–12			
Row name	: card columns 15–22			
Element value	: card columns 25–36			
Row name	: card columns 40–47			
Element value	: card columns 50–61			

RHS cards: The first card is "RHS." Each additional card has the name column REQD. Two row names and matrix values are given per card. For those rows with G parameters, the value given is the square footage of blanks required, though more blanks of those lengths could be used. For those rows with L parameters, the value given is the maximum square footage of blanks permitted. All names and values are left justified.

RHS (Start in column 1).

REQD	*Row Name*	*Element Value*	*Row Name*	*Element Value*
	REQD	: card columns 5- 8		
	Row name	: card columns 15–22		
	Element value	: card columns 25–36		
	Row name	: card columns 40–47		
	Element value	: card columns 50–61		

JCL cards: Three additional cards are required to end the card deck.
Start in column 1.

```
ENDATA
/*
//
```

Example

We used System 6 technology to make 4/4 frame blanks from low-grade white oak thinnings (Reynolds and Araman 1983). Four GCL's were tested using all boards. Yields were high for each operating method, and the optimal yield using all four operating methods to obtain the required blanks was very good. We then made additional tests using these four GCL's with only those boards below No. 3A Common grade. In this example we show the operating methods optimization for the second series of tests to obtain 1,000 square feet of required blanks. The LP matrix is shown in Figure 6. The four GCL's are labeled OME-OMH.

The first three pages show the input card deck. The computer run was named "FRAME 4." In the "ROWS" section we specified that "MINBOARD" was the objective function (row parameter "N"). Blanks 70 to 22 inches long should have at least the square footage shown in the "RHS" (row parameter "G") section. Blanks 19 to 13 inches long should not exceed the square footage shown in the "RHS" section (row parameter "L"). Here we ran into trouble.

When only the poorest boards are used, more salvage length blanks (19, 17, 13 inches long) are made compared to using all boards. We exceeded the 40-square-foot limit of required 13-inch blanks before enough 54-inch-long blanks were made. The LP program shut down when the 40-square-foot limit of 13-inch blanks had been made. So we increased the quantity of salvage length blanks by 900 square feet and ran the program again. Now all blanks were made and an optimization was reached.

The program output is shown on page 27. Under "Section 1 Rows" printout, the minimum board input is 1,760 square feet. The exact quantity of blanks 70 to 22 inches required was made. Originally, we wanted no more than 50 square feet of 19-inch blanks, and we got only 47 square feet. Originally, we wanted no more than 25 square feet of 17-inch blanks, and we got only 12 square feet. Originally, we wanted no more than 40 square feet of 13-inch blanks, but we had to accept 41 square feet to obtain all of the 70- to 22-inch-long blanks required.

Under the "Section 2 Columns" printout, the board quantities for each operating method are shown. Operating method E would use 487 square feet of boards, operating method F 494 square feet, operating method G 582 square feet, and operating method H 197 square feet. Not all blank lengths are made with these four operating methods, but enough additional long blanks are made to allow trimming to shorter blanks. Trim method 70.54 was used to convert 108 square feet of 70-inch blanks to 54- and 13-inch blanks. Trim method 44.22 was used to convert 19 square feet of 44-inch blanks to 22-inch blanks. Trim method 33.29 was used to convert 88 square feet of 33-inch blanks to 29-inch blanks. Trim method 33.27 was used to convert 151 square feet of 33-inch blanks to 27-inch blanks. The quantity of blanks so obtained are included in the "Section 1 Rows" printout. No other trim methods were used.

Columns → RHS

Rows ↓

	OME	OMF	OMG	OMH	TM 70.54	TM 70.44	TM 70.33	TM 70.29	TM 70.27	TM 70.24	TM 70.22	TM 54.44	TM 27.24	TM 27.22	TM 24.22	REQD
MIN BOARD N	1.0	1.0	1.0	1.0												
BL70 G	0.161	0.138			-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0					39.0
BL54 G					0.771							-1.0				83.0
BL44 G	0.209					0.629						0.815				83.0
BL33 G		0.283	0.462				0.943									169.0
BL29 G			0.059					0.829								112.0
BL27 G		0.085							0.771				-1.0	-1.0		166.0
BL24 G			0.043	0.498		0.343				0.686			0.889		-1.0	123.0
BL22 G	0.166			0.052						0.314	0.943			0.815	0.917	110.0
BL19 L	0.019	0.040	0.017	0.042												950.0
BL17 L	0.013	0.003	0.001	0.019												925.0
BL13 L	0.020	0.009	0.005	0.021	0.186				0.186							940.0

Figure 6.—Linear programing matrix.

```
//B0945HWR JOB 00510,REYNOLDS
/*ROUTE PRINT MVS1.RMT04
/*LONGKEY GATCHEL
/*PRICRITY PRIORITY
/*JOBPARM LINES=3
//STEP1  EXEC  LP
//LP.SYSIN DD  *
          PROGRAM
          INITIALZ
          TITLE('SYSTEM 6 OPERATING METHODS OPTIMIZATION FRAME 4')
          MOVE(XDATA,'FRAME4')
          MOVE(XPBNAME,'PBFILE')
          CONVERT('SUMMARY')
          BCDOUT
          MOVE(XOBJ,'MINBOARD')
          MOVE(XRHS,'REQD')
          SETUP
          PICTURE
          VARIFORM
          SOLUTION
          EXIT
          PEND
/*
//GO.SYSIN DD *
NAME           FRAME4
*STUDY 57 E,F,G,H OM  ALL TM BG BOARDS ONLY EXTRA SHORT LENGTHS
ROWS
  N MINBOARD
  G BL70
  G BL54
  G BL44
  G BL33
  G BL29
  G BL27
  G BL24
  G BL22
  L BL19
  L BL17
  L BL13
```

```
COLUMNS
    OME       MINBOARD  1.0       BL70      0.161
    OME       BL44      0.209     BL22      0.166
    OME       BL19      0.019     BL17      0.013
    OME       BL13      0.020
    OMF       MINBOARD  1.0       BL70      0.138
    OMF       BL33      0.283     BL27      0.085
    OMF       BL19      0.040     BL17      0.003
    OMF       BL13      0.009
    OMG       MINBOARD  1.0       BL33      0.462
    OMG       BL29      0.059     BL24      0.043
    OMG       BL19      0.017     BL17      0.001
    OMG       BL13      0.005
    OMH       MINBOARD  1.0       BL24      0.498
    OMH       BL22      0.052     BL19      0.042
    OMH       BL17      0.019     BL13      0.021
    TM70.54   BL70      -1.0      BL54      0.771
    TM70.54   BL13      0.186
    TM70.44   BL70      -1.0      BL44      0.629
    TM70.44   BL24      0.343
    TM70.33   BL70      -1.0      BL33      0.943
    TM70.29   BL70      -1.0      BL29      0.829
    TM70.27   BL70      -1.0      BL27      0.771
    TM70.27   BL13      0.186
    TM70.24   BL70      -1.0      BL24      0.686
    TM70.24   BL22      0.314
    TM70.22   BL70      -1.0      BL22      0.943
    TM54.44   BL54      -1.0      BL44      0.815
    TM54.33   BL54      -1.0      BL33      0.611
    TM54.33   BL19      0.352
    TM54.29   BL54      -1.0      BL29      0.537
    TM54.29   BL24      0.444
    TM54.27   BL54      -1.0      BL27      1.0
    TM54.24   BL54      -1.0      BL24      0.889
    TM54.22   BL54      -1.0      BL22      0.815
```

```
    TM44.33   BL44      -1.0          BL33      0.750
    TM44.29   BL44      -1.0          BL29      0.659
    TM44.29   BL13      0.295
    TM44.27   BL44      -1.0          BL27      0.614
    TM44.27   BL17      0.386
    TM44.24   BL44      -1.0          BL24      0.545
    TM44.24   BL19      0.432
    TM44.22   BL44      -1.0          BL22      1.0
    TM33.29   BL33      -1.0          BL29      0.879
    TM33.27   BL33      -1.0          BL27      0.820
    TM33.24   BL33      -1.0          BL24      0.727
    TM33.22   BL33      -1.0          BL22      0.667
    TM29.27   BL29      -1.0          BL27      0.931
    TM29.24   BL29      -1.0          BL24      0.828
    TM29.22   BL29      -1.0          BL22      0.759
    TM27.24   BL27      -1.0          BL24      0.889
    TM27.22   BL27      -1.0          BL22      0.815
    TM24.22   BL24      -1.0          BL22      0.917
RHS
    REQD      BL70      39.0          BL54      83.0
    REQD      BL44      83.0          BL33      169.0
    REQD      BL29      112.0         BL27      166.0
    REQD      BL24      123.0         BL22      110.0
    REQD      BL19      950.0         BL17      925.0
    REQD      BL13      940.0
ENDATA
/*
//
```

SYSTEM 6 OPERATING METHODS OPTIMIZATION FRAME 4

SECTION 1 - ROWS

NUMBER	...ROW..	AT	...ACTIVITY...	SLACK ACTIVITY	..LOWER LIMIT.	..UPPER LIMIT.	.DUAL ACTIVITY
1	MINBOARD	BS	1759.97076	1759.97076-	NONE	NONE	1.00000
2	BL70	LL	39.00000	.	39.00000	NONE	2.36906-
3	BL54	LL	83.00000	.	83.00000	NONE	3.07271-
4	BL44	LL	83.00000	.	83.00000	NONE	1.64955-
5	BL33	LL	169.00000	.	169.00000	NONE	1.74074-
6	BL29	LL	112.00000	.	112.00000	NONE	1.98036-
7	BL27	LL	166.00000	.	166.00000	NONE	2.12285-
8	BL24	LL	123.00000	.	123.00000	NONE	1.83579-
9	BL22	LL	110.00000	.	110.00000	NONE	1.64955-
10	BL19	BS	47.17715	902.82285	NONE	950.00000	.
11	BL17	BS	12.13836	912.86164	NONE	925.00000	.
12	BL13	BS	41.25840	898.74160	NONE	940.00000	.

SYSTEM 6 OPERATING METHODS OPTIMIZATION FRAME 4

SECTION 2 - COLUMNS

NUMBER	.COLUMN.	AT	...ACTIVITY...	..INPUT COST..	..LOWER LIMIT.	..UPPER LIMIT.	.REDUCED COST.
13	OME	BS	487.38305	1.00000	.	NONE	.
14	OMF	BS	494.08499	1.00000	.	NONE	.
15	OMG	BS	581.74584	1.00000	.	NONE	.
16	OMH	BS	196.75689	1.00000	.	NONE	.
17	TM70.54	BS	107.65240	.	.	NONE	.
18	TM70.44	LL	.	.	.	NONE	.70181
19	TM70.33	LL	.	.	.	NONE	.72754
20	TM70.29	LL	.	.	.	NONE	.72734
21	TM70.27	LL	.	.	.	NONE	.73234
22	TM70.24	LL	.	.	.	NONE	.59174
23	TM70.22	LL	.	.	.	NONE	.81353
24	TM54.44	LL	.	.	.	NONE	1.72832
25	TM54.33	LL	.	.	.	NONE	2.00912
26	TM54.29	LL	.	.	.	NONE	1.19416
27	TM54.27	LL	.	.	.	NONE	.94986
28	TM54.24	LL	.	.	.	NONE	1.44069
29	TM54.22	LL	.	.	.	NONE	1.72832
30	TM44.33	LL	.	.	.	NONE	.34400
31	TM44.29	LL	.	.	.	NONE	.34450
32	TM44.27	LL	.	.	.	NONE	.34612
33	TM44.24	LL	.	.	.	NONE	.64905
34	TM44.22	BS	18.86306	.	.	NONE	.
35	TM33.29	BS	88.36973	.	.	NONE	.
36	TM33.27	BS	151.22290	.	.	NONE	.
37	TM33.24	LL	.	.	.	NONE	.40612
38	TM33.22	LL	.	.	.	NONE	.64048
39	TM29.27	LL	.	.	.	NONE	.00399
40	TM29.24	LL	.	.	.	NONE	.46033
41	TM29.22	LL	.	.	.	NONE	.72835
42	TM27.24	LL	.	.	.	NONE	.49083
43	TM27.22	LL	.	.	.	NONE	.77846
44	TM24.22	LL	.	.	.	NONE	.32315

Reynolds, Hugh W. **System 6: Rough-mill operating manual.** Res. Pap. NE-542. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1984. 27 p.

Includes operating instructions for the System 6 rough mill. Techniques are shown for making standard-size blanks, in all lengths, for each of 13 blank quality/width/thickness combinations.

ODC 836.1:847.1/2

Keywords: Low-grade utilization; hardwood dimension

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984—705-029/503

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**Northeastern Forest
Experiment Station**

Research
Paper NE-543

1984

Quality Response of Even-Aged 80-Year-Old White Oak Trees After Thinning

David L. Sonderman

Abstract

Stem defects were studied over an 18-year period to determine the effect of thinning intensity on quality development of 80-year-old white oak trees. Seventy-nine white oak trees from a thinning study in Kentucky were analyzed from stereo photographs taken in 1960 and 1978. Stem-related defects were measured on the butt 8-foot and second 8-foot sections of each tree. The number of defects per square foot of surface area increased significantly at the heaviest thinning level. The data suggest that heavy thinning has a detrimental effect on potential stem quality.

The Author

David L. Sonderman, research forest product technologist, received a B.S. degree in forestry from West Virginia University in 1962. He joined the Northeastern Forest Experiment Station in June 1962, and was a member of the staff of the Eastern Softwood Timber Quality project until June 1972. Currently, he is with the Northeastern Station's project on Management and Utilization Alternatives for Nonindustrial Private Forests located at Delaware, Ohio.

Manuscript received for
publication 17 October 1983

Introduction

Forest managers have long been interested in increasing volume growth by the use of various silvicultural treatments. Emphasis has been on increasing tree diameter and height growth by regulating residual stand density, but there has been little regard for tree quality. In fact, tree quality is equally important to good volume growth because it provides high value end-products such as veneers and high-grade lumber.

Documentation of research on the effects of stocking on growth rates is much more frequent than documentation of potential quality development. We found that white oaks responded quite differently from other hardwood species reported on. In one study, the relative change in stem quality of 33-year-old white oaks was affected by thinning intensities after 16 years of treatment. The number of live and dead branches greater than 0.3 inch in diameter had increased for all density levels, with the largest increase at the lowest density plots (Dale and Sonderman 1984).

In a study on the response of young northern hardwoods in New Hampshire, Marquis (1969) found that after 5 years there was no reduction in quality due to treatment. In a study of the influence of stand density on stem quality of pole-size northern hardwoods, Godman (1971) found that during a 15-year period the average number of defects per tree did not change except in the type and position of the defects in the lower tree bole. Smith (1977) found that thinning to various tree-density levels did not influence epicormic branching in yellow-poplar after 8 years.

In most of these studies the responses of individual tree characteristics were observed independently. In this paper, we have included individual tree and quality characteristics that we believe are related to potential end-product classes. We are examining the relationship of time on the development of quality-related surface characteristics of trees grown at different levels of residual stand density. Research on hardwood quality has shown that species, age, crown ratio, and stand density are important factors that affect potential stem quality. Usually, limb-related defects and epicormic branches are the bole characteristics most affected by thinning treatments. In this paper, limb-related characteristics should be considered simultaneously to interpret the effect of stand density on their development.

Methods

Data were collected on sample trees from a thinning experiment on the Daniel Boone National Forest, Laurel County, Kentucky. In 1960, sixteen 1-acre plots were established in an 80-year old white oak stand; isolation zones of ½ chain surrounded each plot. Four plots each were thinned to a residual basal area of 20, 40, and 60 ft²/acre, leaving four plots with approximately 80 ft²/acre as the control. Minimum diameter of trees thinned from the plots was limited to 3.6 inches. Originally, all plots were about the same in density, age, size class, species composition, and site quality. Before the initial cutting, the average basal area of the plots was 80 ft²/acre. The average age was 78, the average d.b.h. was 8.9 inches, and the average site index was 63. Tree vigor, spacing, size, and apparent quality based on form, straightness, and freedom of stem branches were the factors used for potential crop-tree selection.

Five trees from each plot were selected at random to study the change in potential tree quality by the stereo-photo technique described by Sonderman (1980). Stereo-photographs were taken from the four cardinal directions around each of the study trees; subsequent stereo-photographs were taken after 18 growing seasons. In this analysis, 79 stereo-photo trees were studied from 8 by 10 stereo-photographic enlargements taken in 1960 and 1978. For each tree we recorded the d.b.h., total height, crown ratio, number and diameter of live and dead limbs, and number of epicormic branches. The trees also were classified by relative quality (Sonderman 1979). Only the limb-related defects were recorded from the stereo-photographs. The remaining variables were measured or observed in the field in 1960 and 1978.

Limb-related variables were analyzed by covariance analysis. The value of the variable at the initial time was used as the covariate.

Results and Discussion

Growth

Stand density affects the diameter, height growth, and crown ratio of trees in different ways. Heavy stand density (80 ft² BA) seems to affect diameter growth more than height growth. Average diameter of the study trees after treatment was 10.59 inches in 1960 and 13.38 inches in 1978. Mean diameter growth increased by 2.8 inches on all trees, with a 22-percent increase in diameter in the 80-ft² plots and a 31-percent increase in the 20-ft² plots. Hilt (1979) found similar diameter-growth trends in relation to stocking.

In this study, mean height growth was highest in the 60-ft² plots, but was not significant due to treatment differences in a similar study by Dale and Sonderman (1984).

Average crown ratio, considered one of the best indicators of the effects of stand density, increased in all treatments except the control. The crown ratio in the control plots (80 ft²) decreased by 7 percent and the crown ratio in the 20-ft² plots increased by 64 percent. The increase in the 20-ft² plots was due to the development of additional epicormic branches, faster growth, and greater retention of branches. Dale and Sonderman (1984) reported highly significant differences between crown length and treatments.

Limb Defects Per Square Foot of Surface Area

Limb defects per square foot of surface area include all live and dead limbs and all overgrowths on the butt 16-foot section of the tree. Analyzing the data by the number of defects per square foot of surface area provides a relative comparison of the effects of stocking on stem quality. Normally, expansion of the surface area will result in a decrease in the number of defects per square foot of surface area—if no new defects develop over time. The following tabulation shows the number of defects per square foot of surface area (butt 16-foot section):

Year	*Residual basal area (ft²/acre)*			
	20	40	60	80
1960	0.139	0.145	0.089	0.102
1978	0.185	0.153	0.095	0.088

The high-density control plots are the only ones that show a decrease in average number of defects after 18 years. The decrease is due to the effect of natural pruning and to the lack of development of epicormic branches that is associated with dense stands. These plots had a 14-percent decrease in the number of defects per square foot of surface area, and a 16-percent increase in surface area. In the 20-ft² plots, there was a 33-percent increase in the number of defects per square foot of surface area and a 24-percent increase in surface area.

Live Limbs

Limbs that were alive and smaller than 0.3 inch in diameter were classified as epicormic branches and those 0.3 inch or larger in diameter were classified as live or dead. The number of limbs was recorded for both the butt 8-foot and second 8-foot sections of each sample tree. In the butt 8-foot section, the number of live limbs and the percentage of trees with live limbs decreased at all density levels between 1960 and 1978 (Table 1). The greatest reduction was in the 60-ft² treatment, which had no trees with live limbs in the butt 8-foot section after 18 years. When comparing the two log sections, the second 8-foot section increased over the butt section in both the proportion of trees with live limbs and the number of live limbs (Table 1). There was an overall reduction in the percentage of trees with live limbs in the second 8-foot section at every density level from 1960 through 1978.

There was no statistically significant ($P < 0.05$) difference in the number of live limbs per tree on the butt 16-foot section after adjusting

for the initial number of live limbs over the 18-year period. However, there was a trend to fewer live limbs per tree as stocking increased. It is apparent that the number of live limbs in the 20- and 40-ft² treatments increased early in the treatment period, because there was an overall increase in the number of dead limbs in these same treatments. This increase in dead limbs developed from an increase in live limbs that subsequently died during the 18-year period.

Diameter of Live Limbs

In 1978, the average diameter of live limbs for the butt 8-foot section of the study trees was more than ½ inch. The exception was the 60-ft² plots, which had no live limbs (Table 2). In the second 8-foot section, the size of the live limbs had fluctuated considerably by 1978—from 1.17 inches in the 40-ft² plots to a low of 0.57 inch in the control plots (Table 2). As the density of the stand increased, the number and size of the live limbs decreased because of natural pruning and limited light. In this study, the diameter of live limbs increased by 31 percent in the 40-ft² plots and by less than 1 percent in the control plots.

Table 1.—Percentage of trees with live limbs in butt 8-foot and second 8-foot sections, 1960–78

Number of live limbs	Residual basal area (ft²/acre)							
	20		40		60		80	
	1960	1978	1960	1978	1960	1978	1960	1978
	BUTT 8-FOOT SECTION							
1–2	20.0	10.0	15.0	5.0	10.5	—	25.0	15.0
3–4	10.0	5.0	—	5.0	—	—	—	—
	SECOND 8-FOOT SECTION							
1–2	60.0	65.0	25.0	20.0	63.2	31.5	50.0	35.0
3–4	15.0	5.0	35.0	10.0	10.5	5.3	15.0	—
5–8	5.0	—	—	—	—	5.3	—	—

Table 2.—Average diameter of live limbs in butt 8-foot and second 8-foot sections, 1960–78

Tree section	Residual basal area (ft²/acre)							
	20		40		60		80	
	1960	1978	1960	1978	1960	1978	1960	1978
	Inches							
Butt 8-foot	0.62	0.58	0.50	0.75	0.50	—	0.50	0.75
Second 8-foot	0.75	0.98	0.85	1.17	0.73	0.65	0.53	0.57

Dead Limbs

In all treatments, the percentage of trees with dead limbs increased in both 8-foot sections over the 18-year period (Table 3). The 20-ft² plots had both the largest increase in the percentage of trees with dead limbs and the largest number of defects in both sections. By contrast, the controls had the smallest increase in the percentage of trees with dead limbs in both sections.

The overall increase in number of dead limbs on the lower density plots resulted from the large increase in live limbs early in the treatment period. These live limbs died later in the treatment period. Dead limbs in the butt 16-foot section showed a significant difference between the 20-ft² treatment and all other treatments ($P < 0.05$). The 20- and 40-ft² treatments were significantly greater than the 60- and 80-ft² treatments ($P < 0.1$). There was no significant difference between the 60- and 80-ft² treatments for the entire 16-foot section.

The development of a dense understory on the lower density plots explains some of the changes in the percentage of trees with dead limbs and the number of dead limbs. Initially, the open condition created in these plots promoted the development of epicormic branches. As the understory developed over the 18 years, it progressively blocked some of the direct sunlight from the butt 8-foot section of the tree, causing limb development to slow. Later, attaining a height of 25 to 30 feet, the understory began blocking sunlight from the entire 16-foot section and suppressing the existing limbs and epicormic branches. This resulted in different limb-related growth rates for each 8-foot section of the tree.

Diameter of Dead Limbs

The average diameter of the dead limbs on the butt 8-foot section was smaller than the average diameter of the dead limbs on the second 8-foot section (Table 4). The size of dead limbs generally increased as stand density decreased.

The second 8-foot section, which encompassed part of the living crown, received more light and as a result had larger dead limbs than the lower 8-foot section. The second 8-foot section of the trees in the 20-ft² treatment had the largest dead limbs, increasing from 0.90 inch in 1960 to 1.53 inches in 1978. This 70-percent increase in the size of the dead limbs illustrates the effect of open stocking on limb development. Part of the increase in the size of dead limbs was caused by the lack of natural pruning, which allowed existing live limbs to remain on the tree and develop. By contrast, the size of dead limbs in the control plots was 0.72 inch in 1960 and only 0.83 inch in 1978.

Epicormic Branches in Both 8-Foot Sections

Table 5 shows the changes in numbers of epicormic branches between 1960 and 1978 for the butt and second 8-foot sections. Three broad categories of epicormic branches were established (Sonderman 1979): (1) trees with no epicormic branches, (2) trees with 1 to 6 epicormic branches, and (3) trees with 7 or more epicormic branches for each 8-foot section.

On the butt 8-foot section, the lowest density treatment had about the same number of epicormic branches per tree after 18 years. The percentage of trees with epicormic branches also remained the same. At all other density levels there was a decrease in the number of epicormic branches per tree, and a similar reduction in the percentage of trees with epicormic branches. In the second 8-foot section, there was a 35-percent reduction in trees with epicormic branches in the lowest density plots.

In the butt 8-foot section, the understory on the 20-ft² plots began blocking the sunlight soon after thinning, causing epicormic branches to develop more slowly. As a result, the percentage of trees with epicormic branches remained about the same over the 18-year period.

In the second 8-foot section, epicormic branches developed faster because of more light for a longer time. Eventually, the understory attained a height of 25 to 30 feet and began shading the second 8-foot section. However, the extra amount of sunlight had allowed the epicormic branches to grow into measureable live limbs, as evidenced by the significant increase in the number of dead limbs.

Table 3.—Percentage of trees with limbs in butt 8-foot and second 8-foot sections, 1960–78

Number of dead limbs	Residual basal area (ft²/acre)							
	20		40		60		80	
	1960	1978	1960	1978	1960	1978	1960	1978
	BUTT 8-FOOT SECTION							
1–2	10.0	30.0	15.0	35.0	—	10.5	10.0	20.0
3–4	—	10.0	—	5.0	—	—	—	—
5–8	—	5.0	—	—	—	—	—	—
	SECOND 8-FOOT SECTION							
1–2	50.0	30.0	50.0	25.0	36.8	42.1	35.0	30.0
3–4	10.0	20.0	20.0	15.0	—	15.8	10.0	20.0
5–8	5.0	25.0	—	35.0	—	—	—	5.0
9–16	—	15.0	—	—	—	—	—	—

Table 4.—Average diameter of dead limbs in butt 8-foot and second 8-foot sections, 1960–78

Tree section	Residual basal area (ft²/acre)							
	20		40		60		80	
	1960	1978	1960	1978	1960	1978	1960	1978
	Inches							
Butt 8-foot	0.75	1.00	0.66	0.66	—	0.63	1.12	0.93
Second 8-foot	0.90	1.53	0.80	1.11	0.85	0.88	0.72	0.84

Table 5.—Percentage of trees with epicormic branches, butt 8-foot and second 8-foot sections, 1960–78

Number of epicormics	Residual basal area (ft²/acre)							
	20		40		60		80	
	1960	1978	1960	1978	1960	1978	1960	1978
	BUTT 8-FOOT SECTION							
1–6	30.0	25.0	60.0	30.0	42.1	—	45.0	5.0
7+	15.0	20.0	5.0	5.0	—	10.5	—	5.0
	SECOND 8-FOOT SECTION							
1–6	65.0	35.0	40.0	50.0	73.7	42.1	55.0	40.0
7+	20.0	15.0	25.0	10.0	5.3	5.3	10.0	5.0

Summary and Conclusion

The information in this report shows important trends in stem quality and growth as related to different levels of residual stand density for white oak trees over time. It must be remembered that the individual characteristics are not independent of one another. For example, there is a pattern of epicormic branches changing to live limbs, live limbs changing to dead limbs, and dead limbs changing to overgrowths. All branch-related defects must be considered simultaneously to interpret the effect of stocking on their development.

Results from this study indicate that in white oak trees measured over time showed that:

1. The number of defects per square foot of surface area decreased as the residual stand density increased.
2. The second 8-foot section of the tree had more live limbs than the butt 8-foot section.
3. Live limbs were substantially larger in the second 8-foot section of the tree.
4. Both the proportion of trees with dead limbs and the number of dead limbs decreased as residual stand density increased.
5. The average number of dead limbs increased almost 4 times from 1960 to 1978 at the lowest density level.
6. There were more epicormic branches in the second 8-foot section of the tree than in the butt 8-foot section.
7. The percentage of trees with epicormic branches on the butt 8-foot section in the open 20-ft² plots did not change. Yet, the percentage of trees with epicormic branches decreased in every other treatment for both 8-foot sections between 1960 and 1978.

Because this study was limited to a single species, site class, and age group, the results can be extrapolated to other species, site classes, and age groups only in very broad terms.

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ODC 228.1: 242: 851: 852.11

Keywords: Silviculture; thinning; bole quality

U.S. GOVERNMENT PRINTING OFFICE: 1984—705-029/510

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Experiment Station**

Research Paper
NE-544

1984

Cost of and Soil Loss on "Minimum-Standard" Forest Truck Roads Constructed in the Central Appalachians

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Manuscript received for
publication 16 January 1984

Abstract

A "minimum-standard" forest truck road that provides efficient and environmentally acceptable access for several forest activities is described. Cost data are presented for eight of these roads constructed in the central Appalachians. The average cost per mile excluding gravel was $8,119. The range was $5,048 to $14,424. Soil loss was measured from several sections of a minimum-standard road. Traffic was regulated the first year and unrestricted the second year. Losses ranged from 44 tons per acre on ungraveled road sections to 5 tons per acre on graveled sections. Soil loss from the graveled sections on the minimum-standard road was about the same as that from higher standard graveled roads.

Introduction

Traditionally, there have been many opinions on the standards to which forest access roads should be built. As a result, such roads have ranged from poorly located ones with little or no water control to well-located and constructed ones with excellent water control. Koger (1978) pointed out several problems in attempting to describe roads in terms of standards. Major variables that have affected standards for forest roads are road costs, projected current and future use, and varying degrees of concern about environmental impacts. Regardless of intended road use, basic standards should include provisions for controlling water, maintaining moderate grades, and good aligning of roads.

Forest roads are a principle concern of land managers in the Appalachian mountains because they represent a significant portion of logging costs and are the source of most environmental concerns during logging operations. Overdesign and some construction practices such as right-of-way clearing, slash disposal, and excessive sloping of banks not only can increase costs but often contribute little to road utility or environmental protection. Because most timber harvesting operations in Appalachia are on private land, forest-road systems should allow a profitable operation, protect other resources, and provide residual value to landowners. Therefore, standards for forest access roads must be realistic and economical with regard to utility and environmental protection.

Since 1977 we have been constructing roads that we call "minimum-standard" truck roads (Kochenderfer and Wendel 1980). Our objective has been to construct roads to the lowest standard that we believe will provide a desirable level of utility and environmental protection at an acceptable cost.

The Minimum-Standard Road

Figure 1 shows a section of a minimum-standard road. These roads are suitable for the large tri-axle trucks commonly used to haul logs in Appalachia and for vehicles with clearances equivalent to those for pickup trucks. Construction costs for a minimum-standard truck road were based largely on the following:

- Roads were constructed from a flagged centerline. There was no formal road design or construction staking.
- Operators experienced in forest-road construction used nothing smaller than a D-6 bulldozer or its equivalent.
- All machines were hired with an operator on an hourly basis. An experienced supervisor-helper remained with the machine operator most of the time.

Figure 1.—Newly constructed minimum-standard truck road on the Fernow Experimental Forest.

- All right-of-way clearing was done with the bulldozer in conjunction with road building. Standing trees were pushed or pulled over and pushed away from the roadbed with the bulldozer. This was done because standing trees are much easier to push out than stumps, and because slash disposal is expensive and does little to improve utility or reduce impacts. Actually removing slash from fill slopes might create erosion.
- Cut banks usually were left vertical. However, if bank height exceeded 5 feet or a ditch line were involved, banks were rough-sloped or benched. Experience has shown that banks stabilize naturally over a 1- to 2-year period. Two to three feet of extra road width was allowed for bank sloughing.
- Culverts were used on all live and intermittent streams. Major seeps were also culverted and ditched as necessary.
- Broad-based dips spaced at intervals of about 200 feet were used to control surface water caused by precipitation (USDA Forest Service 1940; Hewlett and Douglass 1968). Natural grade breaks reduced the number of constructed dips needed.
- Seeding was done with a cyclone seeder since most of the exposed soil suitable for seeding was on the roadbed.

Methods

Costs for road building were determined from a daily tally of man and machine hours on eight minimum-standard forest truck roads that were constructed by the procedures outlined. The hours include all of the delays and downtime actually paid for. Seven of these roads were constructed with a D-6 bulldozer; the eighth was constructed with a D-7 dozer. D-5 and JD-450 bulldozers were used to a limited extent on some roads; their time accounted for less than 5 percent of the total excavation costs on these roads. A backhoe was used to install some of the culverts on one road. Although some of the roads were graveled, gravel costs were not included. Data for each road are shown in Table 1. Width, cut bank height, road grade, and side slope are average values computed from observations made at intervals of 100 feet when the roads were measured. Measurements were made after most bank sloughing had occurred. All of the construction was based on a contracted hourly rate. In addition to making decisions concerning road construction, the road foreman also served as a helper to the dozer operator, e.g., pulling out the winchline, swamping, and installing culverts.

Table 1.—Characteristics of eight "minimum-standard" forest truck roads constructed in the central Appalachians

Road no.	Road length	Road width	Cut bank height	Road grade	Side slope	Azimuth aspect	Number of dips[a]	Culvert			Ditch length	Turnaround		Length of hard rock	Machine used
								Number	Size	Length		Number	Size		
	Miles	*Feet*		*Percent*					*Inches*	*Feet*	*Feet*		*Ft²*	*Feet*	
1	0.81	12.6	3.9	6.9	39.0	SW	22	1	18	39		3	4025		D-6 JD-450
2	0.38	15.5	4.0	4.8	33.1	S	12	1 1	15 18	32 37		2	5580		D-6
3	1.08	16.9	3.9	6.7	29.7	SW	28	2	15	64		5	19184		D-6
4	1.16	15.7	4.1	8.0	31.6	NE	14	7[b] 2	15 15	210 64	1604	1	2000		D-7
5	1.93	15.6	5.1	7.8	43.3	SW	41	8 2 2	15 36 18	236 86 64	662	5	18480	1100	Backhoe D-4 D-6
6	0.78	14.9	4.6	2.7	40.2	S	15	5	15	135	628	3	9690		D-6
7	0.34	15.1	5.1	3.7	47.3	S	5	2	15	64	432	1	2960	211	D-6
8	1.25	15.3	4.4	2.6	38.6	W	30	0				2	5115		D-6 JD-450

[a]Includes natural grade breaks where dozer work is required for outsloping.
[b]30-foot sections of gasline pipe.

Results and Discussion

The eight roads on which data have been collected since 1977 represent many road-building conditions encountered in the central Appalachians. This area is characterized by steep mountains and narrow valleys. Much of the forest land is privately owned in small tracts, which places many constraints on road location. All of the roads were relatively short and located in areas that were unfamiliar to the road locators. Road costs are summarized in Table 2. Rates used for various machines, labor, and culverts are listed in the following tabulation (machine rates include an operator):

Item	*Dollars*
Layout and construction	
Foreman	15/hr
Labor	8/hr
Machine used in excavation	
D-7	60/hr
D-6	50/hr
D-4	35/hr
JD-450	25/hr
Backhoe	25/hr
Culvert	
15-inch gasline pipe (30-foot sections)	7.50/ft
15-inch galvanized	6.00/ft
18-inch galvanized	7.75/ft
36-inch galvanized	19.00/ft

Road Location

An average of about 40 hours was required to plan, reconnoiter, and lay out 1 mile of truck road. Layout often required rerunning grade lines two or three times until the "best" location was found. Road 5 required the most time to lay out, about 50 hours per mile. This road had several large rock outcrops which required changing the location several times. Silversides and Koroleff (1949) recognized the importance of road location: "Once a road is established it is seldom relocated so that if it is improperly located, the users suffer for years after." Road location costs accounted for 8 percent of total road costs.

Table 2.—Cost summary for eight "minimum-standard" forest truck roads constructed in the central Appalachians[a]

Road no.	Road length	Road location		Excavation		Culvert cost/mile	Vehicle cost/mile	Labor cost/mile		Total cost/mile
								Foreman	Other[b]	
	Miles	*Hours/mile*	*Dollars/mile*	*Hours/mile*	*Dollars/mile*	*Dollars*		*Dollars*		*Dollars*
1	0.81	39	585	58 4	2,900 100	371	92	921	79	5,048
2	0.38	42	630	84	4,200	1,264	127	1,267	169	7,657
3	1.08	37	555	69	3,450	356	111	1,028	74	5,574
4	1.16	35	525	93	5,580	1,696	291	935	332	9,359
5	1.93	50	750	25 143 6	625 7,150 210 441[c]	1,839	156	2,606	647	14,424
6	0.78	41	615	84	4,200	1,043	155	1,256	536	7,805
7	0.34	48	720	113	5,650	1,143	134	1,696	286	9,629
8	1.25	39	585	79 8	3,950 200	0	36	686	0	5,457
	Mean		621		4,832	964	138	1,299	265	8,119

[a]Costs and time rounded to nearest whole number.
[b]Labor for culvert installation.
[c]Blasting cost.

Excavation

Excavation as used here includes all the machine time used in construction. It includes all clearing, construction and installation of drainage structures, and all other earth-moving activities. Excavation time ranged from 62 hours/mile (Road 1) to 174 hours/mile (Road 5), and averaged 96 hours/mile. Road 1 was constructed on one of the best road-building soils in this area. No hard rock was encountered, and only one culvert was required. This road also was narrower (12.6 feet) than any of the other roads (Table 1). Road 5 was by far the most difficult of the eight roads to construct. A 1,100-foot section of hard-rock, some of which required blasting, was encountered (Fig. 2). In addition, a considerable amount of time was spent removing several large trees on the right-of-way (Fig. 3). On average, excavation time accounted for 59 percent of the total road cost on the eight roads. Construction of broad-based dips was included in excavation costs. The average number of dips constructed was 22 per mile and this amounted to about 11 percent of excavation costs.

Figure 2.—Section on Road 5 where hard rock was encountered.

Culverts

An average of four culverts/mile of road was used. The number of culverts ranged from none on Road 8 to 8 per mile on Road 4. Most were installed with rock headwalls. Road 8, which required no culverts, was located high on a mountain with a western exposure and on excellent road-building soil. Road 4 had a northern exposure and more active seeps and streams. Road 5 had the highest culvert cost per mile ($1,839). A large part of this cost was for two 36-inch, 40-foot culverts. Most of the culverts were used to drain live seeps. The minimum-size culvert used was 15 inches. Gasline pipe (15-inch) welded into 30-foot sections was used for seven culverts on Road 4. Culverts accounted for 12 percent of total road costs on the eight roads.

Figure 3.—Large tree removed on Road 5.

Vehicles

Vehicle cost includes the machines used during road location and to transport the foreman and laborers. It also includes the vehicles used to haul culverts, tools, and rock for culvert headwalls. Vehicles accounted for 2 percent of total road costs.

Labor

Labor costs include the foreman's wages and cost of other labor used to install culverts. Labor amounted to 19 percent of total road costs. When there is no set of road specifications detailing each phase of construction, the foreman must be able to make on-the-spot decisions concerning clearing limits, road width, culvert placement, ditch requirements, dip locations, and turnouts. Foreman costs averaged 16 percent of road costs while the cost of other labor (installing culverts) amounted to 3 percent of total road costs.

Soil Loss

Reducing road standards does not necessarily increase erosion. On the Fernow Experimental Forest soil loss was measured from both graveled and ungraveled road sections on a newly built minimum-standard road where water was controlled with broad-based dips. Soil loss also was measured from a higher standard road ditched completely with metal culverts spaced about 300 feet apart. This road was graveled with 1-inch crusher-run gravel and the sloped banks have become well stabilized with vegetation since the road was constructed in the 1930's. Average road grades did not exceed 10 percent on either road.

Average annual soil loss on the minimum-standard road was 44 tons per acre on the bare sections and 5 tons per acre from the section graveled with 3-inch clean gravel. Average annual soil loss from the higher standard road graveled with 1-inch crusher-run gravel was 5 tons per acre. In addition to improving utility, gravel greatly reduced soil loss from road surfaces. On newly constructed roads, 3-inch clean gravel usually is used. If the road surface is firmer than normal, e.g., the road has been constructed and used before, 3-inch crusher-run gravel often is used. About 1,100 tons of gravel per mile are required to surface a road to a 4-inch depth. In our area, we use limestone gravel and this adds about $10,000 per mile to road costs. We believe that much of this cost can be borne by eliminating some of the design and construction features required for higher standard roads. In the central Appalachians, where precipitation occurs on average of 1 of every 3 days (Patric and Studenmund 1975) and roads usually do not remain frozen for extended periods, gravel can greatly increase the utility and reduce adverse environmental impacts. We believe that if a road is built at least 1 year before being subjected to heavy use, the amount of gravel required for stabilizing can be reduced. Groves et al. (1979) reported that if the disturbed subgrade is allowed to settle naturally for 6 months to 1 year, the amount of material needed for a 4- to 6-inch depth can be reduced.

In some soils, the content of natural coarse stone is high enough to prevent rutting without gravel during wet periods. Such a road is shown in Figure 4. This road was constructed in the fall, and drainage dips were installed at that time. Hauling was done the following April. Hauling the same volume of timber over an adjacent section of ungraveled road with low content of coarse fragment caused severe rutting.

Figure 4.—Minimum-standard truck road with high content of natural coarse stone.

Conclusions

The minimum-standard truck road fills a need between the "mud road" too often used in Appalachia and costly, higher standard roads. For roads constructed primarily for timber management activities, fire control, or hunter access, we believe that the "minimum-standard" is a good choice. When timber values and projected uses are considered, it is often difficult to justify a better road. The minimum-standard truck road provides a desirable level of utility and environmental protection at an acceptable cost. The average cost per mile for the eight roads, excluding gravel, was $8,119.

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ODC 383.1:383.4:663.26:116.5
Keywords: Forest roads, central Appalachians, construction costs, soil loss

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984—705-029/513

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Research
Paper NE-545

1984

Costs of Logging Thinnings and a Clearcutting in Appalachia Using a Truck-Mounted Crane

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Manuscript received for
publication 1 February 1984

Abstract

Four timber cutting treatments—three levels of thinning and a clearcutting—were applied on 60-year-old mountain stands of Allegheny hardwoods. The stands were logged by a three-man crew using chain saws and a truck-mounted crane. Logging operations were studied, and production rates determined for tree-length logs decked at roadside. Work efficiency and productivity of the logging crew were somewhat higher on the thinning operations than on the clearcut.

Labor, equipment, and road construction costs were determined and applied to production rates. Comparison of logging costs among the four cutting treatments showed that the cost of wood decked at roadside was less for thinnings than for clearcutting. Silvicultural and environmental considerations of truck-crane logging are discussed.

Acknowledgment

The authors gratefully acknowledge the assistance rendered in conduct of this study by the timber management research staff and the Fernow Experimental Forest logging crew, USDA Forest Service, Forestry Sciences Laboratory, Parsons, West Virginia.

Introduction

Eastern hardwood forests abound with wood. However, most of the wood and growth occurs in poletimber and small sawtimber stands, many of which are overstocked. Silviculturists recommend that many of these stands be thinned to improve the quality and size of residual trees and to salvage trees that would die. The increased yield and growth would help meet the Nation's demand for fiber and wood energy, which is projected to more than double by the year 2000.

Because of a lack of markets for small roundwood, thinning of eastern hardwood forests has not been a common management practice. Recent studies (Huyler 1982, Wartluft and Sarles 1982) of two conventional harvesting systems have shown that thinning operations for energy wood in mountain hardwoods are economically marginal. This paper reports logging production rates and costs for thinning and clearcutting operations conducted in the central Appalachians using a somewhat unconventional harvesting system—the truck-mounted crane.

Figure 1.—Overstocked stand of Allegheny hardwoods on Middle Mountain (elevation 3,700 feet) in the Monongahela National Forest, Pocahontas County, West Virginia.

The Study

The harvesting study was conducted on a 60-year-old stand (red oak site index 70) of Allegheny hardwoods located at 3,700 feet on Middle Mountain in the Greenbrier District of the Monongahela National Forest, Pocahontas County, West Virginia. The timber, mainly black cherry and maple, was even aged and overstocked (Fig. 1) with an average of 759 stems (≥1 inch) per acre, averaging 6.2 inches dbh (diameter at breast height) (Table 1).

Table 1.—Stand data for thinned and clearcut blocks of Allegheny hardwoods, Pocahontas County, West Virginia, before cutting

Treatment	Block size	Average number of trees/acre ≥1.0 inch dbh	Basal area/acre	Mean dbh[a]
	Acres		*ft²*	*Inches*
Thinning				
75-percent-level[b]	4.0	609	168.5	7.1
60-percent-level[b]	4.0	732	166.5	6.5
45-percent-level[b]	4.0	788	158.0	6.1
Clearcut	2.0	908	149.9	5.5
Overall	14.0	759	160.7	6.2

[a]Diameter at breast height of tree of average basal area.
[b]Stocking level of residual stand.

Three blocks of four acres each, laid out side by side on a mid-slope location, were thinned to residual stocking levels of 45, 60, and 75 percent in accordance with Roach's (1977) prescriptions for Allegheny hardwoods. A fourth block of 2 acres, located on a flattened ridgetop, was clearcut. Although the stands of timber on the harvested blocks were fairly comparable and suitable for our harvesting study, there were differences. For example, the number of trees per acre ranged from 609 on the 75-percent block to 908 on the clearcut block. Basal area per acre and size of the average tree, however, were highest on the 75-percent block and lowest on the clearcut (Table 1).

Harvesting was done by a three-man crew of experienced loggers using chain saws for felling and a truck-mounted crane for yarding tree-length logs to cold decks at the woods road (Fig. 2). The crane, mounted on a 20-ton, rubber-tired crane carrier, required a 12-foot-wide, graded truck road on which to operate.

From the thinned blocks, the loggers removed trees (merchantable in local markets) 6.0 inches dbh and larger (Fig. 3). The average dbh of the cut trees ranged from 9.2 to 10.5 inches; the average cubic volume of wood and bark ranged from 13.2 to 17.4 cubic feet per stem. The average number of trees and tonnages cut per acre ranged from 71 trees (24 tons) for the lightest thinning to 117 trees (52 tons) for the heaviest (Table 2).

On the clearcut block, 258 merchantable trees averaging 9.1 inches dbh and 13.4 cubic feet in volume were harvested. Total tonnage of logs removed per acre was 89 tons (Table 2). In addition to cutting the merchantable trees, the feller, in the course of his work, felled and lopped nonmerchantable saplings and poles ≥ 1.0 inch dbh.

Figure 2.—Truck-mounted crane used to yard tree-length logs from thinned and clearcut blocks. Maximum yarding distance on slopes was 450 feet.

Figure 3.—Typical assortment of tree-length logs removed in thinnings on Middle Mountain.

Table 2.—Harvest data for merchantable trees cut from thinned and clearcut blocks of Allegheny hardwoods, Pocahontas County, West Virginia

Treatment	Average number of trees/acre ≥6.0 in. dbh	Average basal area	Mean dbh[a]	Average merchantable length[b]	Average merchantable volume[c]	Harvest/acre		
		ft²/acre	*Inches*	*Feet*	*ft³*	*ft³*	*Cords*[d]	*Tons*[e]
Thinning								
75-percent-level[f]	71	33.1	9.2	36.0	13.2	937	10.2	24.1
60-percent-level[f]	102	57.0	10.1	37.1	15.7	1,601	17.4	41.2
45-percent-level[f]	117	70.2	10.5	37.9	17.4	2,039	22.2	52.5
Clearcut	258	115.9	9.1	37.9	13.4	3,455	37.6	89.0

[a]Diameter at breast height of tree of average basal area.
[b]Average length to a 4-inch top dob, or to the limit of merchantability.
[c]Volume of tree-length logs, including bark, calculated using top and butt dob's and merchantable length in the formula for frustum of a cone.
[d]92 cubic feet of wood plus bark per cord.
[e]Determined by applying Timson's (1975) weight/volume ratios for Appalachian hardwoods.
[f]Stocking level of residual stand.

Work measurement studies were conducted to determine felling and yarding production rates and worker efficiency. Each discrete work activity in the tree-felling and yarding cycles was timed using snapback stopwatches. Work delays were also timed and causes noted. Tree and log measurements (Fig. 4) were taken and recorded. Merchantable volumes of trees and tree-length logs were calculated using the frustum-of-a-cone formula. Tree and log weights were computed by applying Timson's (1975) weight/volume ratios for Appalachian hardwoods.

Figure 4.—Measuring tree-length logs at the landing.

Production Rates

Felling

Mean felling production rates (based on productive time) were estimated for each of the four harvests from the tables developed by Sarles and others (in press). These rates were related directly to the average merchantable volume (Table 2) of the cut trees.

To account for nonproductive time, which was caused by various delays, we calculated the worker efficiency factor for each cutting operation. The product of the efficiency factor times production rate per productive hour (PPH) was the production rate per scheduled hour (PSH) (Table 3). The lower efficiency factor for clearcutting was mainly due to nonproductive time used to cut saplings. Even with more than usual assistance from the chokersetter, the feller's daily output was about 24 percent less than his performance in the heaviest thinning.

Yarding

The truck-mounted crane yarded logs using two different techniques and sets of hardware. For distances greater than 100 to 150 feet, logs were yarded using three or four wire-rope chokers. Anywhere from two to four logs per turn were yarded to the log deck at roadside. Logs within 100 to 125 feet or less of the deck were yarded singly using log tongs (Fig. 2). For each setting of the truck crane, part of the logs on the strip being harvested were yarded using chokers, and part were yarded using log tongs. (Of 315 yarding turns that we timed on the four treatment blocks, 48 percent were yarded using chokers, and 52 percent were yarded using tongs.)

Tong yarding was fast—mean turn times averaged less than one-third of mean turn times for chokers (Table 4). This was understandable because yarding distances and load weights were considerably less for tong yarding than for choker yarding.

Table 3.—Hourly and daily mean production rates for felling, limbing, and topping tree-length logs

Treatment	Production rates per productive hour	Efficiency factor	Production rates per scheduled hour	Production rates/day (8 hours)
	Tons	*Percent*	*Tons*	*Tons*
Thinning				
75-percent-level[a]	10.9	63	6.9	55
60-percent-level[a]	11.7	60	7.0	56
45-percent-level[a]	12.8	60	7.7	62
Clearcut	11.2	53	5.9	47

[a]Stocking level of residual stand.

Table 4.—Adjusted mean productive times per turn for truck-crane yarding in thinning and clearcutting operations

Treatment	Mean turn times		
	Chokers[a]	Tongs[b]	Combined[c]
	Minutes		
Thinning			
75-percent-level[d]	4.89	1.44	3.09
60-percent-level[d]	5.09	1.40	3.17
45-percent-level[d]	5.72	1.50	3.53
Clearcut	6.05	1.62	3.74

[a]Adjusted to yarding distance of 225 feet, load weight of 1,962.5 pounds, and 2.5 logs per turn.
[b]Adjusted to yarding distance of 80 feet, load weight of 785 pounds, and 1.0 log per turn.
[c]Adjusted using weighting factor of 0.48 for chokers and 0.52 for tongs.
[d]Stocking of residual stand.

Combining the dissimilar turn times for choker and tong yarding to arrive at an overall production rate representative of the truck-mounted crane presented a challenge. So, we modeled productive time per turn for (1) chokers and (2) tongs as functions of one or more independent variables from a variable pool that included yarding distance, slope, load volume and weight per turn, number of logs per turn, mean weight per log, and a number of other functions and interactions. For choker and tong yarding, an analysis of covariance indicated that individual models were required for each of the four cutting treatments—eight regression models in all. The variables—in various combinations—that gave the best fit for choker yarding models were yarding distance, load weight per turn, number of logs per turn, mean weight per log, and the interaction of yarding distance and mean weight per log. The variables that gave the best fit for tong yarding models were yarding distance and the interaction of yarding distance and load weight per turn.

To compare yarding production rates among the four cutting treatments, mean productive times per turn for choker and tong yarding were adjusted (using the appropriate regression model) to selected values:

	Tongs	*Chokers*
Yarding distance, feet	80	225
Load weight per turn, pounds	785	1,962.5
Number of logs per turn	1.0	2.5
Mean weight per log, pounds	785	785
Proportion of total turn, percent	52	48

Mean production rates in tons PPH were calculated for each cutting treatment using the combined adjusted mean turn time (Table 4) and mean load weight per turn as follows:

$$\text{Production rate in tons PPH} = \frac{60 \text{ minutes}}{\text{combined adjusted mean turn time, minutes}} \times \frac{\text{mean load weight, pounds}}{2{,}000 \text{ pounds}}$$

For example, the mean production rate for the medium thinning was calculated as follows:

$$\text{Production rate in tons PPH} = \frac{60 \text{ minutes}}{3.17 \text{ minutes}} \times \frac{1{,}350.2 \text{ pounds}}{2{,}000 \text{ pounds}}$$

$$= 18.93 \text{ turns per hour} \times 0.675 \text{ tons per turn}$$

$$= 12.8 \text{ tons per hour}$$

Mean production rates PPH for each cutting treatment are given in Table 5. (Tables of mean production rates PPH for a range of yarding distances, turn weights, and numbers of logs are available for each operation from the authors.) Efficiency factors for yarding on each cutting treatment are also given. Mean production rates PSH were calculated as the product of production rate PPH times the efficiency factor. Yarding output per 8-hour day is the product of mean production rate PSH times 8 (Table 5).

Table 5.—Hourly and daily mean production rates for yarding tree-length logs

Treatment	Production rates per productive hour	Efficiency factor	Production rates per scheduled hour	Production rates/day (8 hours)
	Tons	*Percent*	*Tons*	*Tons*
Thinning				
75-percent-level[a]	13.1	52	6.8	54
60-percent-level[a]	12.8	50	6.4	51
45-percent-level[a]	11.5	55	6.3	50
Clearcut	10.8	43	4.6	37

[a]Stocking of residual stand.

Investment and Costs

Equipment for the logging system used in this study included two new chain saws, a used truck-mounted crane, and a new pickup truck. The capital invested in these machines totaled $25,646 in 1982 (Table 6). Compared to other combinations of new felling and skidding equipment—some costing as much as $200,000—the investment in this system can be considered very moderate.

The cost to own and operate the machines, plus wages and fringe benefits for the three crew members, was $31.58 an hour (Tables 7 and 8). This system operating cost was converted to cost per ton harvested by dividing $31.58 by the tonnage yarded to the road per scheduled hour (Table 5). For the lightest to the heaviest thinnings, the respective costs per ton were $4.64, $4.93, and $5.01. And for the clearcut, the cost was $6.87 per ton (Table 9).

Road building costs are highly variable depending on the terrain, soil and rock conditions, construction standards, and so on. For this study we estimated road costs using Kochenderfer and Wendel's (1980) data for an operation similar to ours. Based on their tractor time of 57 hours per mile to bulldoze and construct drainage dips and 1982 machine and labor rates ($45 per hour for a D-6), we figured that a newly constructed woods road, 12 feet wide with most grades 10 percent or less, would cost approximately $3,000 per mile. This amount includes an allowance for three 20-foot culverts, but no gravel.

With roads spaced at 350-foot intervals, the truck-mounted crane can log, uphill, approximately 42.4 acres per mile of road. Thus, cost of the woods road at $3,000 per mile converts to $70.75 per acre. Dividing $70.75 by tons harvested per acre on each cutting (Table 2), road costs per ton were $0.79 for the clearcut and $2.94, $1.72, and $1.35, respectively, for the lightest to the heaviest thinnings (Table 9).

Table 6.—Equipment prices and other assumptions used to compute hourly machine costs

Item	Price (1982)	Economic life	Scheduled hours/year	Utilization factor
	Dollars	*Years*	*Number*	*Percent*
Chain saw	646	2	1,800	53 to 63[a]
Chain saw (spare)	646	2	1,800	20
Truck-mounted crane (used)	15,240	5	1,800	43 to 55[a]
Pickup truck (for crew, tools, parts, and fuel)	9,114	3	2,000	25

[a]Varied among the four operations studied.

Table 7.—Hourly machine rates for equipment

Item	Fixed[a]	Variable[b]	Total
	----------*Dollars*----------		
Chain saw	0.195	1.001[c]	1.196
Chain saw (spare)	.195	.339	.534
Truck-mounted crane (used)	2.360	2.840[c]	5.200
Pickup truck	1.740	1.290	3.030
Totals	4.490	5.470	9.960

[a]Fixed cost based on scheduled hours per year includes depreciation, 13-percent cost of capital, insurance, and taxes.
[b]Variable cost based on actual operating hours includes fuel, lubricants, filters, tires, chains and bars, maintenance, and repairs.
[c]Average variable cost for thinnings and clearcutting.

Table 8.—Hourly labor costs

Job	Wage	Fringe benefits[a]	Total
	----------*Dollars*----------		
Crane operator	6.50	2.02	8.52
Feller	5.50	1.70	7.20
Chokersetter	4.50	1.40	5.90
Totals	16.50	5.12	21.62

[a]In West Virginia, estimated at 31 percent for Social Security, Workmen's Compensation, and Unemployment Insurance.

Table 9.—Logging costs per ton for tree-length logs decked at roadside using a truck-mounted crane harvesting system

Treatment	System operating cost	Road cost	Total logging cost
	Dollars per ton		
Thinning			
75-percent-level[a]	4.64	2.94	7.58
60-percent-level[a]	4.93	1.72	6.65
45-percent-level[a]	5.01	1.35	6.36
Clearcut	6.87	.79	7.66

[a]Stocking of residual stand.

After the operating and road costs for the truck-mounted crane system were determined and converted to dollars per ton, the cutting treatments were compared on a cost basis. Total logging cost for tree-length logs decked at roadside was lowest ($6.36 per ton) for the 45-percent-level thinning and highest ($7.66 per ton) for the clearcut. The cost per ton for the 45-percent-level thinning was $0.29 less than the 60-percent-level thinning, $1.22 less than the 75-percent-level thinning, and $1.30 less than the cost of the clearcutting (Table 9).

Discussion

Most loggers and foresters would not expect the cost of logging the clearcutting to be more than the cost of logging the thinnings. Is there an explanation? If so, it must be either in costs or productivity of the harvesting system.

Costs

Two principal costs were involved in logging the four cuttings: hourly operating costs and road construction costs. As has been shown in tables 7 and 8, hourly operating costs for equipment and labor were the same for the truck-mounted crane system regardless of cutting operation.

When comparing the equipment machine rates of this system to other systems that might have been used, the hourly rate ($5.20) for the used truck-mounted crane is an important factor. This reasonable cost for a cable yarder contributed significantly to the low-cost performance of all cutting treatments. By comparison, the hourly rate for a used rubber-tired cable skidder might be 2 or 3 times as much. For example, if a used rubber-tired cable skidder (90-hp class) at $10.56 per hour had been used, operating costs per ton (assuming the same crew size and production rates) would have increased 15 percent, and more roads would have been required.

Productivity

For the purposes of this study, productivity was equated with the amount of wood in tree-length logs yarded and decked at roadside landings per scheduled hour. Two components in this determination were: production rate per productive hour and the efficiency factor. Each component was affected to some degree by characteristics of the sites, the stands, and the cutting treatments. For example, we found that the flatness of the clearcut block had a detrimental effect. It took the chokersetter longer to pull out the cable over flat ground than on the downhill slopes where gravity provided assistance. This showed up as a 35 percent longer out-haul time per 100 feet of yarding distance. Log hookup times were also 35 percent longer on the clearcut block because of the increased amount of slash on the ground from cutting more trees per acre. The slowup in out-haul and hookup times accounted for much of the increase in yarding turn times for clearcutting and, hence, in the lower production rate per productive hour.

The single biggest reason, however, for reduced productivity on the clearcut operation was the reduced efficiency of the crew as reflected in nonproductive delays. Delay time per turn for clearcutting averaged 4.7 minutes—57 percent more than the average delay time of 3.0 minutes per turn for thinnings. The most significant reasons for delays in clearcutting were: work other than yarding (2.07 minutes per turn) and hangups (1.18 minutes per turn). Both of these related directly to the larger number of trees cut per acre and the increased amount of slash and number of stumps that hampered yarding (Fig. 5). Work other than yarding included time lost while the chokersetter assisted the feller with directional felling, hung-up trees, and cutting nonmerchantable saplings and poles. It also included time working on the landing to make room to deck the increased number of logs coming off the clearcut block.

Silvicultural Considerations

To comply with the clearcutting prescription, all saplings (1.0 to 5.5 inches dbh) had to be felled and lopped. This work, classed as a stand regeneration operation, usually is not considered as a part of logging. More and more, though, loggers are removing saplings on clearcuts as part of their harvesting contracts. Many saplings are destroyed by logging and do not have to be felled, and, with intensive utilization practices, larger saplings are often harvested for whole-tree chipping.

Sometimes, however, loggers are compensated for slashing the nonmerchantable material. If so, two methods of payment seem to be practiced: an allowance applied against the cost of stumpage, or a direct payment on an acreage basis. The latter is used more when the operation is conducted after harvest.

Figure 5.—Heavy slash on clearcutting block was one cause of reduced yarding production and efficiency.

Miller (1984) determined costs for reducing sapling basal area in thinned cherry-maple stands. It cost almost $15.00 per acre to remove 20 square feet of basal area. To remove 25 square feet of saplings on a clearcut, the cost would be proportionately more, or about $19.00 per acre. Spread over the total 89 tons harvested from the clearcut, the cost of sapling reduction would be $0.21 per ton. Allowances of $0.40 to $0.80 per ton (depending on stand and terrain conditions) were used in the past by one firm for compensating logging contractors. If we select an allowance midrange of these three figures, $0.50 per ton ($44.50 per acre), logging cost for clearcutting reduces to $7.16 per ton, a cost in line with those for the thinnings.

Logging Damage

Damage to trees in the residual stand is always a concern when logging, especially in thinnings where the residual stems are expected to increase in value for future harvests. Lamson and Miller (1982) determined logging damage of residual dominant and codominant trees in the same cherry-maple stands discussed in this report. Blocks logged with the truck-mounted crane suffered less damage than stands logged with a rubber-tired cable skidder. Only 5 percent or less of the residual dominant and codominant trees on blocks logged with the truck crane were classed as high risk trees for the respective 75, 60, and 45 percent thinning operations. With the rubber-tired skidder, 7, 13, and 22 percent of the number of stems were classed as high risk trees for the respective 75, 60, and 45 percent thinning operations. On steep terrain, the truck-mounted crane reduces residual stand damage because of increased lift of the logs and greater operator control over yarding through use of the 25-foot swing boom.

Environmental Concerns

Visual impacts of logging—road scars on hillsides, damaged trees, and muddy streams—arouse public feelings against timber harvesting. Compared to wheeled-tractor logging, the truck-mounted crane "walks" relatively lightly on the land. Timber stand damage is lessened, and fewer roads and landings are required for truck-crane logging. Disturbance of soil and streams due to roads, landings, and stream crossings is reduced (Kochenderfer 1977).

Soil erosion is minimized since truck-crane logging harvests 2 to 3 times more acreage per mile of constructed road compared to wheeled-tractor logging. Sediment production from a truck-crane logged watershed was similar to yields summarized for undisturbed forest plots and small watersheds in the Eastern United States. Soil disturbance was minimized by taking necessary precautions with road building and critical stream channel areas (Kochenderfer and Wendel 1980).

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Investigates the effects of thinning and clearcutting on the cost of logging using a truck-mounted crane for yarding and chain saws for felling. Work measurement studies of the harvesting operations were conducted on three 4-acre blocks of timber marked for thinning and on a 2-acre clearcut. Worker efficiency and productivity were higher for thinning than for clearcutting. Reasons for the difference are discussed. Comparisons of logging costs among the four cuttings showed that the cost of wood delivered to roadside was less for logs removed from the thinned blocks than from the clearcut. Silvicultural and environmental aspects of truck-crane logging are discussed.

ODC 666

Keywords: Logging costs; thinning; clearcutting; cable yarding; time study; production rates; Allegheny hardwoods

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984—705-029/525

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1984

Quality Response of 29-Year-Old, Even-Aged Central Hardwoods After Thinning

David L. Sonderman

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Manuscript received for
publication 13 February 1984

Abstract

Describes the quality response of a 29-year-old upland hardwood stand grown for 6 years under different levels of residual stand density. Both the number of defects per square foot of surface area and the number of epicormic branches changed under different stocking levels. The results suggest that the effect of stocking on potential stem quality of certain species may be substantial even after a few years of treatment.

Introduction

In the last decade, much research has been done on diameter and height growth responses associated with various silvicultural treatments designed to regulate density of even-aged upland hardwood stands (Hilt 1979). But there has been little research on comparing the response of quality-related tree characteristics to those treatments. Stem quality of trees can be changed, sometimes adversely, by regulating the stand density. Recent studies (Dale and Sonderman 1983) have shown that live and dead branches on young white oak trees grown under different density levels increased the most on the lowest density plots. Sonderman (1983) found that the number of defects per square foot of surface area for 80-year-old white oaks increased significantly at the heaviest thinning level. Godman (1968) showed that after 16 years, heavy stem release of sugar maple shortened the average clear bole length. Godman and Books (1971) also showed that stem quality improvement in northern hardwoods was related to residual stand density.

In this study, 6-year changes in individual limb-related characteristics for several species have been summarized in relation to different levels of residual stand density. Limb-related defects are the greatest deterrent to stem quality and the most important consideration in managing a stand for maximum quality development. Hardwood quality research has shown that potential stem quality also is affected by species, age, crown class, and crown ratio. However, limb-related defects and epicormic branches still are the bole characteristics that are affected most by thinning treatments, and they should be considered simultaneously when interpreting results.

The Stand

The trees selected for this study are located on the Vinton Furnace Experimental Forest in southern Ohio. The stand originated on an 8-acre demonstration plot after a clearcut in 1954. The area was originally a mature, even-aged, fully stocked, mixed oak stand with an average site index of 64. The stand was divided into twenty-two 1/10 acre-plots with ½-chain isolation strips around each treatment area. In 1976, the basal area of the young stand was 93 square feet before thinning. Thinning treatments of 30, 50, and 70 percent stocking were applied to groups of plots. Five plots were used as a control. After treatment, the stand was composed of aspen, red maple, mixed oaks, yellow-poplar, black cherry, and hickory. A total of 338 trees are included in the study. Four species groups were used in the analyses (Table 1). A miscellaneous group, which included black cherry and hickory, accounted for only a few trees and was not included in the analyses.

Table 1.—Number of trees used in study, by species group and stocking level

Species group	Stocking level (%)			
	30	50	70	Control
Oak	19	22	24	16
Yellow-poplar	15	3	19	8
Red maple	29	9	21	46
Aspen	7	34	42	24

Methods

A quality classification system (Sonderman and Brisbin 1978) was used to systematically measure the external characteristics of all trees 3.6 inches or larger in diameter at breast height (d.b.h.). All measurements, including limb-related measurements taken on the first and second 8-foot section of each tree, were made before thinning in the spring of 1976 and in 1982. Limb size had to be at least 0.3 inch in diameter to be measured.

Tree quality characteristics (Sonderman 1979) recorded were:

- d.b.h.
- total height
- crown ratio
- number of live limbs on the 1st and 2nd 8-foot section
- number of dead limbs on the 1st and 2nd 8-foot section
- diameter of the largest live limb on the 1st and 2nd 8-foot section
- diameter of the largest dead limb on the 1st and 2nd 8-foot section
- number of epicormic branches on the 1st and 2nd 8-foot section

These characteristics were summarized by species, plot, and treatments; limb-related variables were analyzed by covariance analysis. The value of the variable at initial time was used as the covariate.

Results and Discussion

Diameter Growth

The effect of stocking on diameter growth over the 6-year period is evident. Mean diameter growth of sample trees in the 30 percent stocking plots was almost twice as much as on the controls (Table 2). Hilt (1979) reported similar trends in diameter growth in relation to stocking from a much larger data base representing the largest trees. Aspen and yellow-poplar had the highest diameter growth in all treatments. Red maple was next and the oaks had the slowest growth. In the control, the oaks had the least diameter growth of all species compared.

Height Growth

The effect of stocking on height growth (Table 2) follows a different pattern than diameter growth. Trees grown at levels of stocking where crowding of stems occurs tend to have greater height growth than diameter growth (Toumey and Korstian 1947). Maximum height growth of all species combined occurred between 50 and 70 percent stocking and averaged slightly more than 2 feet a year from 1976 to 1982. The trend was similar for individual species. The 30 percent plots and the control plots had the least overall change except for aspen. In the control, aspen grew 3 times faster than other species.

Crown Ratio

Crown ratio is the ratio of live crown length to total tree height. Changes in crown ratio after 6 years of thinning treatments are shown in Table 2. For all species combined there was a reduction of crown ratio in all treatments except for the 30 percent treatment. The increase in crown ratio was caused by the open conditions created by heavy thinning. Opening a stand provides additional growing space and light needed to develop epicormic branches and promote the development of live branches. This contributes to a downward extension of the crown and results in an increase in crown ratio.

Looking at the species individually, crown ratios for yellow-poplar increased nearly twice as much as other species in the 30 percent plots. Most species increased in crown ratio in the 30 percent plots and decreased in the control. In the control after 6 years, aspen changed in crown ratio only by 0.3 percent. Red maple, which had the most uniform change in crown ratios, was affected the least by treatment.

The 30 percent treatment, regardless of species, showed significantly greater crown ratio than the other treatments ($P < .005$). However, within the same treatment there was no significant difference in crown ratio between oaks and all species combined.

Table 2.—Summary of average tree characteristics in 1976 and 1982, by species group and stocking level

Species group	Stocking level (%)							
	30		50		70		Control	
	1976	1982	1976	1982	1976	1982	1976	1982
	D.b.h. (Inches)							
Oak	6.1	8.0	5.2	6.6	5.4	6.5	6.0	6.7
Yellow-poplar	6.5	9.6	4.8	7.9	6.1	8.3	6.5	8.1
Red maple	5.5	8.0	4.9	7.2	5.5	7.2	5.2	6.4
Aspen	7.2	10.2	6.6	9.4	6.9	9.1	6.9	8.9
	Height (Feet)							
Oak	48.9	53.2	41.9	53.4	41.5	51.2	48.9	52.6
Yellow-poplar	54.2	59.4	42.0	63.3	46.5	58.3	59.5	62.4
Red maple	48.6	56.4	42.1	53.0	42.3	56.7	51.5	54.6
Aspen	60.1	66.8	51.8	68.8	52.3	68.4	63.3	72.9
	Crown Ratio (Percent)							
Oak	33.2	39.9	30.9	24.0	28.6	22.5	25.8	27.5
Yellow-poplar	26.6	41.9	43.7	35.6	34.9	25.0	25.0	19.4
Red maple	37.2	45.8	36.7	37.5	38.4	35.2	28.3	25.9
Aspen	41.7	49.3	38.7	31.1	41.3	28.9	29.1	28.8
	Defects/ft² Surface Area (Number)[a]							
Oak	0.235	0.157	0.165	0.091	0.188	0.064	0.094	0.045
Yellow-poplar	.029	.060	.316	.052	.048	.015	.029	—
Red maple	.143	.120	.320	.191	.221	.082	.222	.074
Aspen	.402	.084	.369	.152	.427	.185	.308	.171

[a]Live and dead limbs, butt 16-foot section.

Live and Dead Limb Defects Per Square Foot of Surface Area

Both volume and total surface area of the bole increase as the tree grows. Expansion of the surface area expressed in square feet may show an increasing or decreasing number of defects per square foot of surface area, depending on how many existing and new defects come and go. This is apparent in Table 2, which shows an overall reduction in the number of live and dead limb defects per square foot of surface area in the butt 16-foot section after 6 years.

Aspen showed by far the greatest reduction in number of live and dead limb defects per square foot of surface area over all treatments. Yellow-poplar and red maple showed the least change of live and dead limbs in the 30 percent plots. The oaks displayed a low but uniform reduction in live and dead limb defects per square foot of surface area throughout all treatments.

When combining all species, the number of live and dead limb defects per square foot of surface area in both the 70 percent and control plots each decreased by about 61 percent from 1976 to 1982. However, there was no significant difference among treatments and species.

Comparing limb defects per square foot of surface area for oaks after 6 years, the 30 percent treatment was significantly greater than the other treatments ($P < .13$).

Epicormic Branches

When a tree stem changes, as in sudden full exposure to sunlight,

dormant buds on the stem begin to grow and develop into epicormic branches. These epicormic branches can develop into small live limbs if allowed to grow in sunlight under conditions of open stocking.

In this study, epicormic branches were grouped to facilitate counting on each tree section. The groups are:

0 = No epicormic branches
1 = 1 to 6 epicormic branches
2 = 7+ epicormic branches

Silviculturists attempt to regulate the development of epicormic branches by maintaining different levels of stocking and favoring species that are not prolific epicormic sprouters. Some of the species included (Table 3) are considered prolific epicormic sprouters. For example, red maple showed an increase in the number of epicormic branches in both the butt and the second 8-foot section as the stocking level decreased. Both sections increased the most at the 50 percent level.

At all stocking levels, the oaks increased in the percentage of trees with epicormic branches; the largest increases were in the 50 and 70 percent plots. The oak trees had a somewhat uniform distribution of epicormic branches in both the butt 8-foot section and the second 8-foot section. This was not the case for many of the other species groups.

In the second 8-foot section, the percentage of yellow-poplar trees with epicormic branches increased at all treatment levels. Percentages were 3 times greater than the original figure for the 30, 50, and 70 percent levels. Percentages in the control increased only by one-third.

Table 3.—Percentage of trees with epicormic branches in butt 8-foot and second 8-foot sections 1976–82, by species

Number of epicormic branches	Stocking level (%)							
	30		50		70		Control	
	1976	1982	1976	1982	1976	1982	1976	1982
OAK								
Butt 8-Foot Section								
0	70.0	15.8	86.4	4.5	96.0	20.8	73.7	6.3
1-6	20.0	42.1	9.1	27.3	4.0	41.7	21.0	62.5
7+	10.0	42.1	4.5	68.2	—	37.5	5.3	31.2
Second 8-Foot Section								
0	65.0	5.3	86.4	—	92.0	12.5	57.9	—
1-6	15.0	15.8	9.1	9.1	8.0	25.0	31.6	37.5
7+	20.0	78.9	4.5	90.9	—	62.5	10.5	62.5
YELLOW-POPLAR								
Butt 8-Foot Section								
0	75.0	53.3	100.0	—	90.0	52.6	100.0	37.5
1-6	25.0	46.7	—	100.0	10.0	42.1	—	62.5
7+	—	—	—	—	—	5.3	—	—
Second 8-Foot Section								
0	68.7	13.3	100.0	33.3	75.0	26.3	62.5	50.0
1-6	25.0	66.7	—	33.4	25.0	63.2	37.5	37.5
7+	6.3	20.0	—	33.3	—	10.5	—	12.5
RED MAPLE								
Butt 8-Foot Section								
0	90.0	10.4	100.0	11.1	100.0	38.1	82.6	37.0
1-6	10.0	44.8	—	44.4	—	47.6	15.2	56.5
7+	—	44.8	—	44.5	—	14.3	2.2	6.5
Second 8-Foot Section								
0	83.3	6.9	100.0	11.1	100.0	38.1	76.1	23.0
1-6	16.7	37.9	—	33.3	—	33.3	23.9	52.2
7+	—	55.2	—	55.6	—	28.6	—	23.9
ASPEN								
Butt 8-Foot Section								
0	100.0	71.4	76.5	50.0	97.7	69.0	100.0	75.0
1-6	—	28.6	20.6	50.0	2.3	31.0	—	25.0
7+	—	—	2.9	—	—	—	—	—
Second 8-Foot Section								
0	100.0	85.7	88.2	73.5	100.0	69.0	100.0	45.8
1-6	—	14.3	11.8	26.5	—	31.0	—	54.2
7+	—	—	—	—	—	—	—	—

Aspen showed little change in the percentage of trees with epicormic branches in the butt 8-foot section. In the second 8-foot section, the proportion of aspen trees with epicormic branches increased the most in the control plots. On all plots, the number of epicormic branches on the second 8-foot section never exceeded six branches.

Live Limbs

Limbs were classified by number, size, and condition (live or dead). Limb size had to be at least 0.3 inch in diameter to be considered; anything smaller was classified as an epicormic branch. Red maple showed the greatest reaction to treatment (Table 4). In 1982, the percentage of red maple trees with live limbs in the butt 8-foot section was 45 at 30 percent stocking level and 22 at 50 percent stocking. The 70 percent and control plots showed no live limb development in the butt 8-foot section.

In the second 8-foot section, the percentage of red maple trees with live limbs at 30 percent stocking was 10 in 1976 and 86 in 1982. At 50 percent stocking, the percentages were 11 in 1976 and 56 in 1982, the percentage of trees with live limbs decreasing as stocking increased. The number of live limbs ranged from 1 to 16 limbs on the 30 percent plots to only 1 to 2 limbs on the control plots.

In comparing the butt and second 8-foot sections of the tree, the percentage of yellow-poplar trees with live limbs in 1982 was 13 for the butt 8-foot section and 60 for the second 8-foot section. The second 8-foot section usually contains more live limbs.

The oaks responded to the lowest stocking treatment—52 percent of the trees had live limbs in the second 8-foot section in 1982. In 1976, the oaks were free of live limbs in the 30 percent plots. In the 50 and 70 percent plots, the oaks accounted for 32 and 17 percent of the trees with live limbs. The control plots showed little change.

Table 4.—Percentage of trees with live limbs in butt 8-foot and second 8-foot sections 1976–82, by species

Number of live limbs	Stocking level (%)							
	30		50		70		Control	
	1976	1982	1976	1982	1976	1982	1976	1982
OAK								
Butt 8-Foot Section								
0	100.0	57.9	100.0	86.4	100.0	95.8	100.0	100.0
1–2	—	42.1	—	13.6	—	4.2	—	—
Second 8-Foot Section								
0	100.0	47.4	100.0	68.2	100.0	83.3	94.7	100.0
1–2	—	36.8	—	27.3	—	16.7	5.3	—
3–4	—	5.3	—	4.3	—	—	—	—
5–8	—	10.5	—	—	—	—	—	—
YELLOW-POPLAR								
Butt 8-Foot Section								
0	100.0	87.7	100.0	100.0	100.0	100.0	100.0	100.0
1–2	—	13.3	—	—	—	—	—	—
Second 8-Foot Section								
0	100.0	40.0	33.3	100.0	85.0	84.2	100.0	100.0
1–2	—	40.0	33.3	—	10.0	10.6	—	—
3–4	—	20.0	33.4	—	—	5.2	—	—
5–8	—	—	—	—	5.0	—	—	—
RED MAPLE								
Butt 8-Foot Section								
0	100.0	55.2	100.0	77.8	100.0	100.0	100.0	100.0
1–2	—	31.0	—	11.1	—	—	—	—
3–4	—	10.4	—	—	—	—	—	—
5–8	—	3.4	—	11.1	—	—	—	—
Second 8-Foot Section								
0	90.0	13.8	88.9	44.5	76.2	42.9	89.1	87.0
1–2	6.7	51.7	—	33.3	14.3	47.6	10.9	13.0
3–4	3.3	20.6	—	—	9.5	9.5	—	—
5–8	—	10.5	11.1	11.1	—	—	—	—
9–16	—	3.4	—	11.1	—	—	—	—
ASPEN								
Butt 8-Foot Section								
0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Second 8-Foot Section								
0	100.0	100.0	97.1	100.0	100.0	100.0	100.0	100.0
1–2	—	—	2.9	—	—	—	—	—

One reason for the increase in the percentage and number of trees with live limbs is that many of the small shoots and twigs that were less than 0.3 inch in diameter in 1976 and classified as epicormics grew larger in diameter by 1982 and, therefore were classified as measurable live limbs. Under heavy thinning, most trees with epicormic branches will feather out and develop more epicormic branches. Some of these epicormic branches will become live limbs in a short time.

When comparing all species, treatment differences for live limbs were significant ($P < .001$). In the 30 percent treatment alone, there was an increase of 1.8 live limbs over the control. When separating out only the oak species, treatment differences for live limbs were significant ($P < .089$).

Diameter of Live Limbs

The average diameter of the largest live limbs in 1976 and 1982 is shown in Table 5. The diameter of live limbs was larger on the second 8-foot section than the butt 8-foot section. On the butt 8-foot section, the oaks, yellow-poplars, and red maples increased in live limb size at both the 30 and 50 percent stocking. The 70 percent and control plots showed little change.

In the second 8-foot section, the average size of the largest live limbs appeared somewhat uniform for the 6-year period. Red maple had the greatest change, with limb size decreasing in all treatments except the control. Because the second 8-foot section usually encompasses part of the living crown in the younger trees, it receives more light than the lower bole section. Consequently, the development of live limbs on the second 8-foot section is not at the same rate as on the butt 8-foot section.

Table 5.—Average diameter of the largest live limbs in butt 8-foot and second 8-foot sections 1976–82, by species

Species	Stocking level (%)							
	30		50		70		Control	
	1976	1982	1976	1982	1976	1982	1976	1982
	Inches							
Butt 8-Foot Section								
Oak	—	0.68	—	0.50	—	—	—	—
Yellow-poplar	—	.50	—	—	—	—	—	—
Red maple	—	.53	—	.50	—	—	—	—
Aspen	—	—	—	—	—	—	—	—
Second 8-Foot Section								
Oak	—	.94	—	1.03	—	1.12	—	—
Yellow-poplar	—	1.16	1.20	—	.91	1.08	—	—
Red maple	1.08	.84	2.00	.84	1.75	1.41	1.15	1.95
Aspen	—	—	1.25	—	—	4.00	—	—

Dead Limbs

Two important factors that affect the presence of dead limbs in trees are species and stand density. Species is important because of inherent differences caused by growth, vigor, shade tolerance, and natural pruning. Stand density is important because of its effect on the factors just cited.

Aspen had the largest percentage of trees with dead limbs and the largest number of dead limbs in the butt 8-foot section (Table 6). In all treatments, aspen showed a reduction in the percentage of trees with dead limbs in the butt 8-foot section over the 6-year period. The 70 percent plots had the greatest reduction in the percentage of trees with dead limbs, and the 30 percent plots had the least reduction. Other species showed similar trends for dead limbs in the butt 8-foot section.

Analysis of the data for the upper 8-foot section shows aspen with both the largest percentage of trees with dead limbs and the largest number of dead limbs. For red maple, the percentage of trees with dead limbs in the second 8-foot section decreased from 83 percent in 1976 to 38 percent in 1982 in the 30 percent plots, and from 96 to 44 percent in the control plots. Trends were similar for many other species.

Table 6.—Percentage of trees with dead limbs in butt 8-foot and second 8-foot sections 1976-82, by species

Number of dead limbs	Stocking level (%)							
	30		50		70		Control	
	1976	1982	1976	1982	1976	1982	1976	1982
OAK								
Butt 8-Foot Section								
0	50.0	57.9	59.1	81.8	60.0	83.3	73.7	93.7
1-2	35.0	36.8	40.9	13.6	24.0	8.3	26.3	6.3
3-4	15.0	5.3	—	4.6	4.0	8.4	—	—
5-8	—	—	—	—	12.0	—	—	—
Second 8-Foot Section								
0	15.0	36.8	9.1	31.8	16.0	50.0	31.6	43.8
1-2	25.0	42.1	31.8	40.9	44.0	41.7	52.6	43.7
3-4	40.0	10.5	45.5	22.7	8.0	—	5.3	12.5
5-8	15.0	—	13.6	4.6	24.0	8.3	10.5	—
9-16	5.0	10.6	—	—	8.0	—	—	—
YELLOW-POPLAR								
Butt 8-Foot Section								
0	81.3	86.7	66.7	100.0	75.0	94.7	100.0	100.0
1-2	18.7	13.3	—	—	20.0	5.3	—	—
3-4	—	—	33.3	—	5.0	—	—	—
Second 8-Foot Section								
0	62.5	80.0	33.3	66.7	65.0	68.4	62.5	100.0
1-2	37.5	13.3	—	—	25.0	31.6	37.5	—
3-4	—	6.7	66.7	33.3	10.0	—	—	—
RED MAPLE								
Butt 8-Foot Section								
0	76.7	89.7	44.4	88.9	47.6	80.9	65.2	80.4
1-2	20.0	10.3	44.4	11.1	47.6	19.1	30.4	17.4
3-4	3.3	—	11.2	—	4.8	—	4.4	2.2
Second 8-Foot Section								
0	16.6	62.1	—	22.2	4.8	28.6	4.3	56.5
1-2	53.4	37.9	22.2	55.6	28.6	61.9	39.1	34.8
3-4	20.0	—	33.4	22.2	28.5	9.5	45.6	6.5
5-8	10.0	—	44.4	—	38.1	—	11.0	2.2
ASPEN								
Butt 8-Foot Section								
0	28.6	42.8	5.9	38.2	14.0	59.5	29.6	58.3
1-2	14.2	42.9	32.3	41.2	44.2	30.9	29.6	33.3
3-4	28.6	14.3	38.3	17.7	20.9	7.2	29.6	8.4
5-8	28.6	—	20.6	2.9	16.3	2.4	11.2	—
9-16	—	—	2.9	—	4.6	—	—	—
Second 8-Foot Section								
0	—	28.6	—	5.9	—	11.9	3.7	—
1-2	—	28.6	5.9	29.4	11.6	28.6	—	20.9
3-4	—	28.6	8.8	23.5	21.0	16.6	22.3	20.8
5-8	71.4	14.2	67.7	38.3	53.3	33.3	48.1	50.0
9-16	28.6	—	17.6	2.9	13.9	9.6	—	8.3

The response of the oaks to treatment showed a reduction in the percentage of trees with dead limbs as the stocking increased. However, there was no significant difference among treatments in the number of dead limbs for the oak group.

Diameter of Dead Limbs

The average diameter of the largest dead limbs on the butt 8-foot section (Table 7) was smaller than the average diameter of the dead limbs on the second 8-foot section. Analyzing all species for both 8-foot sections, the size of dead limbs in 1982 decreased in all treatments except for the control. One reason for the larger dead limbs in the dense control plots is that the smaller dead limbs naturally pruned off over the 6-year period, leaving only the larger remaining limbs to be counted during the second measurement period.

Summary and Conclusions

Results of this research are not intended as guidelines for applying cultural treatments to forest stands. Instead, they allow the woodland manager to look at what might happen to a forest stand in a short time at different levels of stocking. The results have limited application because only one site class and one age group was used. The comparisons and quantifications in this paper are the beginning of a long-term research study to determine the effects of different cultural practices on tree quality.

In 6 years, there have been numerous changes due to treatment in both the rate of growth and the bole quality of certain species groups. The defect characteristics covered in this study are not independent of each other. There is a sequence of events that occurs simultaneously. For example, epicormic branches that develop will grow into live limbs, live limbs die and become dead limbs, and dead limbs fall off and become overgrowths. It is equally important to note that growth and quality sometimes develop naturally even when nothing is done to the forest stand. As evidence of this, some of the control plots had better quality than some of the treated plots. Drastic cutting schemes sometimes are applied to stimulate the growth rate; this adversely affects bole quality. Therefore, there is a trade-off between growth and quality when both are objectives.

Table 7.—Average diameter of the largest dead limbs in butt 8-foot and second 8-foot sections 1976–82, by species

Species	Stocking level (%)							
	30		50		70		Control	
	1976	1982	1976	1982	1976	1982	1976	1982
	Inches							
	Butt 8-Foot Section							
Oak	1.06	0.56	0.77	0.81	1.32	1.30	1.40	1.75
Yellow-poplar	1.49	.50	.75	—	.80	.75	—	—
Red maple	1.42	1.10	.55	.50	1.06	.75	.85	1.08
Aspen	.60	.56	.58	.55	.56	.54	.53	.52
	Second 8-Foot Section							
Oak	1.51	1.54	1.29	1.17	1.59	1.55	1.24	2.08
Yellow-poplar	1.29	.50	1.12	1.00	1.25	.95	.92	—
Red maple	1.08	1.03	.77	.85	1.44	1.11	.83	1.13
Aspen	1.07	1.14	1.00	.93	.97	.88	.77	.76

Some of the findings in this study indicate that:

- Diameter (d.b.h.) growth increased with an increase in growing space.
- Average crown ratio of all trees combined increased only at the lowest stocking level.
- Live and dead limb defects per square foot of surface area decreased as stocking increased.
- The number of live limbs and the percentage of trees with live limbs decreased as stocking increased.
- There were more dead branches than live branches on the butt 16-foot log regardless of stocking level.
- The second 8-foot section of the butt 16-foot log of the tree had more and larger live and dead limbs than the bottom 8-foot section.
- The number of epicormic branches and the percentages of trees with epicormic branches increased as the stocking level declined for all species combined.
- Aspen and yellow-poplar increased the most in diameter growth after 6 years.
- Red maple outperformed all other species in height growth in the 30 percent plots.
- Aspen had fewer limb defects per square foot of surface area than any other species.
- At 30 percent stocking, yellow-poplar was the only species to show an increase in limb defects per square foot of surface area.

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Toumey, James W.; Korstian, Clarence F. **Foundations of silviculture.** New York: John Wiley and Sons; 1947. 468 p.

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Describes the quality response of a 29-year-old upland hardwood stand grown for 6 years under different levels of residual stand density. Both the number of defects per square foot of surface area and the number of epicormic branches changed under different stocking levels. The results suggest that the effect of stocking on potential stem quality of certain species may be substantial even after a few years of treatment.

ODC 228.1:242:851:852.11

Keywords: silviculture; thinning; bole quality

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984—705-029/520

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Research
Paper NE-547

1984

Rate of Value Change in Pennsylvania Timber Stands

Owen W. Herrick

Abstract

Data from remeasured Pennsylvania forest inventory plots revealed that during a 13-year period the compound rate of value change in uncut hardwood forest stands averaged 4.7 percent, and ranged from −5.5 to 18.8 percent. No well-defined means for predicting a stand's rate of value change could be identified. However, some measures of initial stand condition can be used to get a general indication of what to expect in stands with management potential. For example, stands with the highest rates of value change (averaging 7.5 percent) have (1) Tree of average basal area less than 5 inches in diameter; (2) less than 10 percent of their basal area in large sawtimber-size trees; and (3) some yellow-poplar, northern red oak, and/or black oak.

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Manuscript received for
publication 19 January 1984

Investigations into the rate at which timber increases in value generally have recognized the benefits of concentrating timber investment capital in well-stocked stands of pole- and small sawtimber-size northern hardwoods. Additional guidelines that indicate what rates of value change to expect of various stands of timber would aid people who have to make decisions about managing forest land.

An *expectation index* such as average rate of value change for forest stands could be useful in comparing timber stands and rating prospective stand management options. This paper reports results from analyses of statewide forest inventory measurements that quantify value change in hardwood timber stands, and provide further understanding of the link between timber stand characteristics and prospective value change.

Background

Given available markets for the species, tree value is influenced by diameter, merchantable height, and quality. The rate of change in tree value generally is based on estimates of prospective change in these attributes applied in the compound interest expression:

$$r = \left[\frac{V_n - V_o}{V_o} + 1\right]^{\frac{1}{n}} - 1$$

where r is the compound interest rate of value change, n is the period of time considered (often 10 years), V_n is the value of the tree n years hence, and V_o is its current value.

Generalized results from a series of studies (Leak et al. 1968; Mendel 1969; Mendel and Trimble 1969; Trimble and Mendel 1969; Grisez and Mendel 1972; Mendel et al. 1973) that have used the expression cited to evaluate projections of hardwood tree value can be summarized as follows:

- Rate of value increase is inversely related to initial tree diameter (assuming initial diameter meets minimum merchantability specifications).
- High-vigor trees (greatest diameter growth rate) have higher rates of value increase than trees of low vigor.
- Improvement in tree quality results in much higher rates of value increase than increases due to growth alone.
- Trees that increase in merchantable height usually show greater rates of value increase than trees that add no merchantable height.

The unique characteristics of a timber stand can be captured in rate of value change calculations by aggregating the value of individual trees and their potential development. Evaluations of silvicultural treatment possibilities for the stand often are handled similarly, making projections of the growth and value of trees in the future stand and focusing treatment results within a relatively short planning period.

The Study

More than *estimates* of growth and value are needed to develop expectation indexes that can serve as benchmarks of average rate of value change for timber stands. The rate of value change over a time period is determined by initial stand value and the relationship between the values at the beginning and end of the time period. Accordingly, the foundation for an index or average rate of value change is a record of actual timber stand change registered over an interval between measurements.

The USDA Forest Service updates statewide timber resource information approximately every 10 years. Part of the updating process includes remeasuring a network of permanent forest inventory plots in each state. Pennsylvania was remeasured during 1978 (Considine and Powell 1980) and 331 plots from that inventory are the basis for this analysis of rate of value change in hardwood forests between the 1965 and 1978 surveys.

Tree merchantable height, diameter (d.b.h.), and tree grade (based on butt-log grade measures) were converted to board-foot and cubic-foot volumes (Scott 1979, 1981). The volumes were then translated into dollar values to express the rate of value change on each forest inventory plot between 1965 and 1978. The dollar values are based on tree-value conversion standards (Mendel et al. 1976; DeBald and Mendel 1976). These standards reflect a tree's net worth as 4/4-inch lumber and/or pulpwood, allowing for the cost of conversion. The same (current) dollar-value standards were applied to both 1965 and 1978 survey measurements to evaluate the stand's development and not allow valuation items that are irrelevant to biological change to get in the way. This use of constant value standards avoids effects of inflation and changes in timber prices that occurred during the period.

Timber stand characteristics thought to correlate with the rate of value change were used as predictor variables to analyze rate of change. These variables are measures of:

Site class
Physiographic class
Timber stand age
Average tree diameter
Tree species composition (%)
Forest type
Trees/acre
Basal area (BA)/acre
Diameter of tree of average BA
Timber stocking (%)

Timber volume:
- Board feet/acre
- Cubic feet/acre

Timber quality:
- % Growing-stock trees
- % Sawtimber in each tree grade

Timber stand-size composition:
- % Sapling-size trees
- % Pole-size trees
- % Small sawtimber trees
- % Large sawtimber trees (15 inches +)
- % 4-inch diameter-class trees
- % Softwood species

Timber value:
- Average tree value
- Initial stand value
- % High-value species ($80+/Mbf)
- % Medium-value species ($50–$80/Mbf)
- % Low-value species ($50/Mbf)

The timber stand variables were screened as potential predictors of rate of value change using stagewise multivariate procedures including automatic interaction detection (AID).

Results

Between 1965 and 1978, inventory plots in the hardwood forests of Pennsylvania had a 3.7 percent average rate of value change. Tree cutting took place in one-fourth of these hardwood stands. When I include only the forest stands that had no timber cutting activity between surveys, the average rate of value change was 4.7 percent. These rates of change ranged from −5.5 to 18.8 percent (Fig. 1).

Despite the wide variety of potential predictors, analyses failed to identify associations between rates of value change and timber stand characteristics that would be useful in a predictive sense. Only loosely defined patterns of relationship showed up between characteristics representing initial timber stand conditions and the resulting rates of value change.

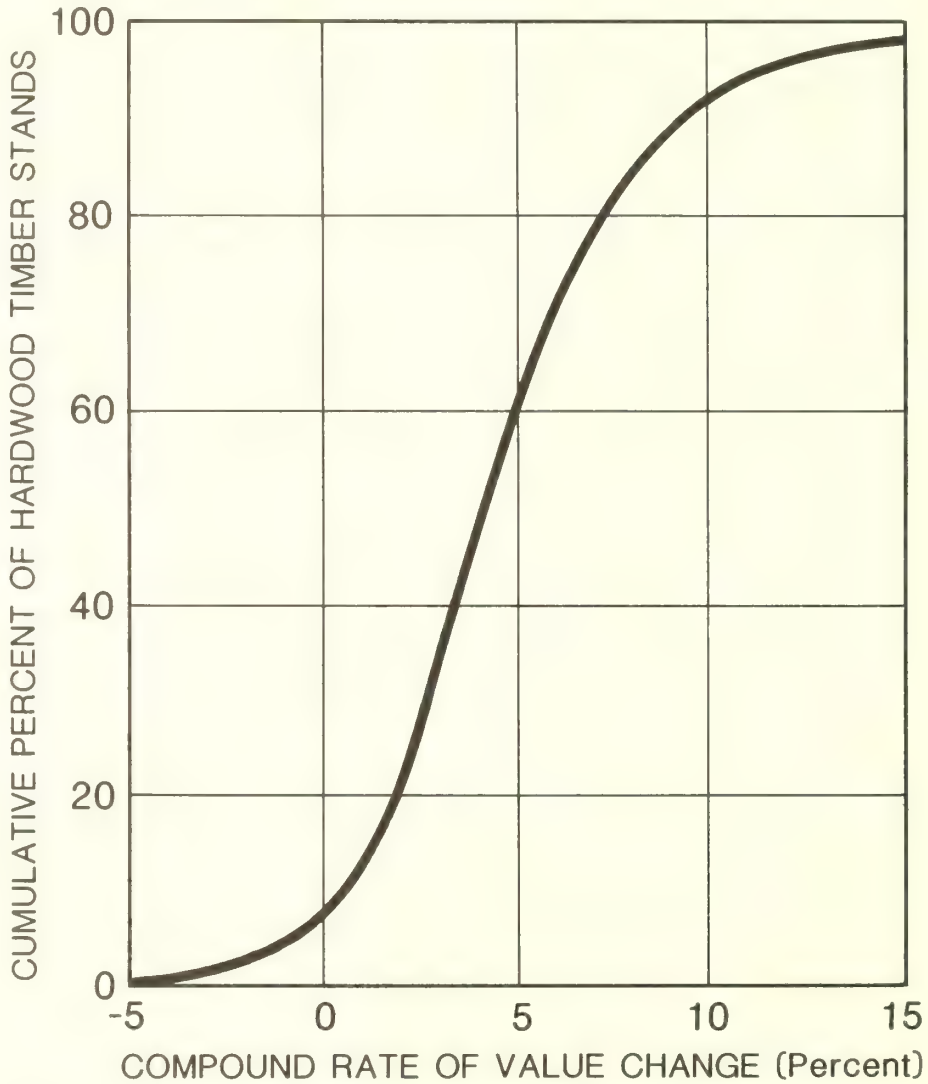

Figure 1.—Compound rate of change in timber value for hardwood forests in Pennsylvania, 1965–78.

Analyses were then concentrated on a subset of the data that included only plots from timber stands with adequate potential to achieve acceptable utilization of the site. That is, the initial stand condition was above the C-line that most stocking guides use to represent a position where 10 years of growth will achieve the lowest limit of acceptable stocking (Gingrich 1967). Stands below the C-line definitely are understocked and ordinarily would not be candidates for decisions requiring a rate of value change index.

This subset of timber stands with "management potential" had rates of value change that ranged from −3.0 to 11.9 percent, and a 4.3 percent average. Again, no useful predictive relationship was evident between initial timber stand characteristics and subsequent rates of value change. Results from AID analysis only loosely defined the structural pattern using initial stand condition measures of tree size, density, species composition, and quality (Fig. 2). For example, stands with the highest rates of value change in these hardwood forests have:

- Tree of average basal area less than 5 inches in diameter,
- Less than 10 percent of their basal area in large sawtimber size trees.
- Some yellow-poplar, northern red oak, and/or black oak.

These conditions identify them as members of Group 9, where rates of value change average 7.5 percent. In addition to this highest rate group, five others (Groups 8, 13, 17, 18, and 19) fell at or above the 4.3-percent statewide average rate of value change for these above C-level stands.

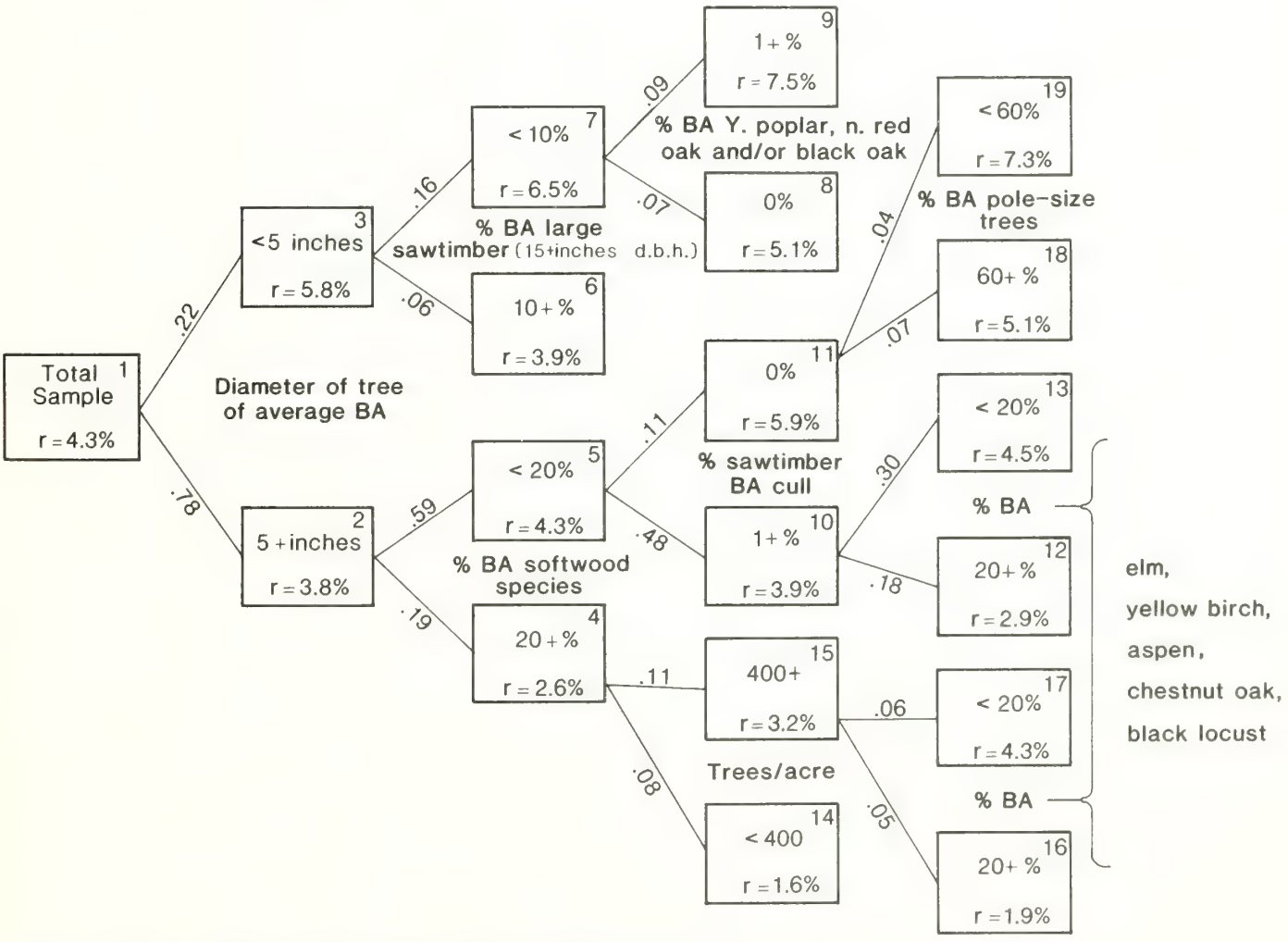

Figure 2.—Guide for estimating rates of value change in hardwood forests. A timber stand is assigned to a value-change group on the basis of characteristics of the stand. The average rate of value change 1965 to 1978 is shown for each group. Decimal fractions on each leg show the portion of the Pennsylvania sample in that group.

Conclusion

It has been said before (Mendel et al. 1973) but it's worth repeating: *dollar value* increase reflects the change in value of trees resulting from increases in diameter, merchantable height, or improvement in quality. A *rate of value* increase, on the other hand, accounts for the initial investment in capital (the value of the trees at the beginning of the period) that must be made to attain the dollar-value increase (added value by the end of the period). The rate of return on the investment (rate of value change) over the period is determined by the initial value and the relationship between the values at the beginning and end of the time period. Consider the following example:

Initial value (V_o)	*Ending value* (V_n)	*Change in value*	*No. of years*	*Rate of value change*
Dollars				*Percent*
10.00	15.00	5.00	10	4.14
50.00	55.00	5.00	10	0.96

In both cases there was a $5.00 change in value. But in the first case, its smaller investment in capital ($10 versus $50) clearly has a greater impact on the resulting rate of value change over the 10 years.

It is the timberland owner who determines the financial objectives of his or her ownership. On the basis of the definitions mentioned, will it be dollar-value increase regardless of the amount of capital investment? Or will it be a prescribed rate of return on the capital investment?

From a financial standpoint, the responsibility for choosing a proper course of action for handling a particular stand of timber rests with the owner, too. Once financial objectives are sorted out—dollar-value increase or rate of return on investment—it remains to determine the value-growth status of the timber stand. I looked at recently remeasured forest inventory plots in Pennsylvania to determine rates of value change in hardwood forests. The plots indicate that uncut hardwood timber stands in Pennsylvania are increasing in value at a rate of 4.7 percent, on average. But wide variation was evident in the rates of change during the 13-year period between inventories—from −5.5 to 18.8 percent. These results are appropriate where gross change estimates are desired. However, the results are limited as a management tool for foresters and landowners. The comprehensive analyses of these data yielded no well-defined predictive relationships between site characteristics or initial timber stand conditions and subsequent rates of value change.

A predictor or expectation index of rate of value change would be most useful. But only general notions seem possible when judging potential rate of value change in hardwood timber stands. Measures of tree size, stand density, species composition and quality can help. They represent key characteristics of initial timber stand conditions that can be used to pigeonhole stands with management potential into very loosely defined rate of value-change groups. These groups, with average rates of value change ranging from 1.6 to 7.5 percent, can serve as useful baselines for comparing timber stands and prospective stand management options.

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Data from remeasured Pennsylvania forest inventory plots revealed that during a 13-year period the compound rate of value change in uncut hardwood forest stands was 4.7 percent, and ranged from −5.5 to 18.8 percent. No well-defined means for predicting a stand's rate of value change could be identified. However, some measures of initial stand condition can be used to get a general indication of what to expect in stands with management potential. For example, stands with the highest rates of value change (averaging 7.5 percent) have (1) Tree of average basal area less than 5 inches in diameter; (2) less than 10 percent of their basal area in large sawtimber-size trees; and (3) some yellow-poplar, northern red oak, and/or black oak.

ODC 653:748

Keywords: Compound interest; financial objectives; hardwood forests

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984—705-029/521

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Paper NE-548

1984

Forest Management Guidelines for Controlling Wild Grapevines

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Manuscript received for
publication 20 January 1984

Abstract

Grapevines (*Vitis* spp.) are becoming a major problem for forest managers in the Appalachians, especially when clearcutting is done on highly productive hardwood sites. Grapevines can reduce tree quality and growth, and eventually kill the tree. Silvical characteristics of grapevines are discussed. Forest management guidelines are given for controlling growth of grapevines. The control guidelines are applied to mature and immature stands using herbicides and mechanical treatments. The grapevine-arbor concept is suggested as a means of regulating the control treatments for timber and wildlife interests.

Forest Management Guidelines for Controlling Wild Grapevines

Contents

Introduction 1

Growing Sites 1

Growth and Reproductive Characteristics 1

- Growth 1
- Flowering 2
- Seed production 2

Grapevine Control in Forest Management 3

Herbicides 4

Grapevine Arbors 6

Stand Silvicultural Treatments 7

- Mature stands—uneven-age management (other partial cuts) 7
- Mature stands—even-age management 7
- Young immature stands—even-age management 9

Summary and Management Recommendations 11

Literature Cited 14

Figure 1.—(A) Grapevines in a young immature hardwood stand. (B) Grapevines and snow combined to bend, break, and uproot trees in this young immature hardwood stand.

Introduction

Wild grapevines (*Vitis* spp.) are becoming a major problem for the forest manager in many areas of the Appalachians. A few years after clearcutting, it is not unusual to find large numbers of grapevines growing in young stands on good to excellent hardwood sites—where the faster growing, more valuable timber exists. Often the reproduction in hardwood stands is excellent, but the presence of grapevines can convert portions of these excellent stands to a mass of grapevines.

Grapevines damage hardwood trees by breaking tops and limbs, twisting and bending the tree bole, and uprooting trees, thus reducing tree quality and eventually killing the tree (Fig. 1). Once grapevines get into the tree crowns, especially in young stands, the potential for future production of quality timber products is severely reduced. No tree damage information related to grapevines has been reported; however, as the number of grapevines per acre increases, more trees have grapevines in crowns, and thus, a higher risk in loss of quality. Many forest managers are concerned about grapevines and want information on growth control.

Wildlife managers are also concerned about measures to control grapevines because the vines produce food and cover for many species of wildlife. The U.S. Fish and Wildlife Service indicates that at least 80 species of birds and a large number of animals eat grape berries (Shutts 1968). Martin and others (1951) report that black bear, raccoon, quail, grouse, turkey, and a host of songbirds eat grapes. Deer browse foliage and stems in the spring and early summer and eat fallen leaves during the winter months (Massey 1961). Birds often use the stringy bark for nest construction, and squirrels build leaf nests in trees with grapevines in the crowns (Martin et al. 1951, Sanderson et al. 1980). Grapevines grow quickly in clearcut openings and, according to Crawford (1971), often produce the only dependable food for wildlife during the early years after a tree regeneration cutting practice. Also, during the summer, grapevines provide excellent escape and nesting habitat for songbirds.

Thus, because of the importance of grapevines to wildlife and because of concern that grapevines reduce tree quality, the control of grapevines growing in a forest stand is highly controversial. However, considerable research has been done on grapevine control, and we know much about grapevine characteristics and response to control treatments. We review the research and provide recommendations for controlling the development of grapevines in given conditions. Users must decide how or what portion of these guidelines to implement.

Considerable research information is available for two species of wild grape, summer grape (*V. aestivalis* Michx.) and its variety silverleaf grape (*Var. argentifolia* Munson). Although wild grapes range throughout most of the Eastern United States, Shutts (1974) indicated that grapes are not common in the northern part of the range.

Growing Sites

Wild grapevines grow on a wide range of soil and site conditions. Often grapevines grow best under moderately moist conditions in dense ravines on southeastern slopes where organic matter has accumulated (Shutts 1968). In West Virginia, grapevines were directly related to site quality, that is, as the site quality increased, grapevines became more abundant (Trimble and Tryon 1979). In Virginia, Shutts (1968) reported six grapevines on every good site compared to one on every poor site. In a later report, Shutts (1974) stated that vines are less resistant to disease on the good moist sites.

Growth and Reproductive Characteristics

Growth

Grapevines in the Appalachians are similar to other woody plants in that each year a growth ring is added to the ring-porous stem (Trimble and Tryon 1979, Stiles 1980). Also, vines if wounded just before or during the growing season, characteristically bleed sap. In West Virginia, this bleeding occurs from early spring to about mid-September.

Wild grapevines sprout prolifically when cut, the stems produce epicormic branches when exposed to sunlight, and the vines root or layer easily. Grapevines are intolerant of shade; prolonged shade reduces growth and will kill the vines.

Grapevines are supported by tendrils that enable the vines to climb

and advance on vegetation. Trimble and Tryon (1979) suggest that most grapevines become attached to the tree crown when the trees are young. Grapevine shoot growth begins later in the growing season than that for other plants, and shoot elongation starts slowly for several weeks, followed by periods of rapid growth. Shutts (1968) reported that while shoot growth is rapid, diameter growth is slow. A 50-year-old vine may have a diameter at ground line of only 1.5 inches. Normally sprout shoot growth is rapid. Annual shoot growth of some young stump sprouts was 15 feet or more (Trimble and Tryon 1979). However, grapevine seedlings grew slower than many tree species. Two growing seasons after clearcutting, grapevine seedlings averaged 0.5 feet tall, yellow-poplar 1.1 feet, and black cherry 2.2. However, the grapevine seedlings grew about as fast as yellow-poplar the first year, but during the winter, many grapevine tops had died. Other vegetation such as blackberries outgrew young grapevine shoots. Trimble and Tryon (1979) observed 70,000 grapevine seedlings per acre the first year after clearcutting, and 5 years later 1,975 grapevines per acre survived competition of other plants. Of the survivors, 139 per acre were climbing the forest vegetation, but not causing any major damage to the tree boles or crowns.

Flowering

Wild grapes normally produce male and female flowers on separate vines from mid-May to early July (Fernald 1950). Some vines also produce perfect flowers which means that a single vine may produce seed—thus even "male" vines are capable of bearing seed (Strausbaugh and Core 1952). The flower pollen is disseminated by wind, rain, insects, and animals. In North Carolina, Della-Bianca (1978) observed that flowers bloomed and were pollinated during the first 2 weeks in June, and tiny grape berries were seen in late June. Frosts did not seem to have any effect on flowering.

Seed Production

Grape seed crops are variable and fluctuate from year to year, but moderate seed crops occur in most years. Grapevines can produce seed the third year after establishment (Shutts 1968), and the seed normally ripens to a dark purple in September and October (Massey 1961). Overhead shading of grapevines results in poor grapevine seed production. Grape seed can remain on the vine throughout the winter, but Shutts (1968) and Della-Bianca (1978) found the greatest amount of seed on the ground about mid-November. Dispersion of seed is largely by wind, animals, and gravity; however, inclement weather, such as high winds accompanied by rain and snow, can increase seed dispersion (Della-Bianca 1978). Periodically, large quantities of seed are produced and the seed can remain viable in the soil duff for many years. Wendel (1981) reported that about 3 percent of the grape seed stored in the soil had the potential to germinate annually and this percent was consistent throughout the years for at least an 11-year period.

Della-Bianca (1978) reported that an average of 96 vines per acre, with an expected 50:50 male to female vine ratio, produced about 1,012 grape clusters per acre per year for 2 years. If the average cluster had 42 berries, about 42,500 berries per acre would be produced (Fig. 2). Also, if each berry contained 3 seeds (range normally 2 to 6), 127,500 seeds per acre could be produced annually. In another study, Shutts (1968) found that six female vines produced about 9,350 grape berries or 28,050 seeds in one season. Shutts further reported that the number of grape clusters per vine increased with the diameter of the vine. However, wild grape seed is susceptible to insect and disease damage. A common disease, black rot (*Guignardia bidwellii*), destroyed 40 percent of the seed crop (Shutts 1968). Also, Curculio beetles (*Craponius inaequalis*) destroyed more than 50 percent of the seed crop (Della-Bianca 1978, 1979). Thus, of the total seed produced in a poor year, we might expect less than 10 percent of the seed production to be available for seed germination. However, 10 percent of an estimated average seed crop could still yield 12,750 available grape seeds per acre.

Although frost does not have much effect on flowering, excessive moisture (rain or high humidity) leads to the development of fungal diseases that destroy the fruit (Shutts 1974). The shoots of the grapevine are subject to both cold and heat injury. A sudden rise in temperature in late spring may result in damage to the shoot tip. Spring frosts often damage foliage if warm weather and rapid growth precede a sudden drop in temperature (Shutts 1974). Overhead shading minimizes the production of grape berries (Della-Bianca 1978).

Figure 2.—Clusters of grape berries.

Grapevine Control in Forest Management

Grapevine control must be consistent with management objectives. If the objective is to grow only high-quality timber, then elimination of all grapevines could be the control treatment. If wildlife development is the sole management objective, then grapevine growth and reproduction could be maintained or stimulated. However, in most situations forest managers want to grow good-quality timber and at the same time encourage wildlife. To meet this objective, grapevines should be controlled by treatments that provide enough grapevines for recommended wildlife purposes, while trying to keep grapevines out of the crown of trees designated for the production of quality timber. Thus, forest managers must consider a number of situations when controlling grapevines.

Usually, most grapevine problems exist on the better sites (oak site index 70 and higher). Grapevines also become a more serious problem to forest managers when silvicultural practices such as clearcutting are used instead of partial-cutting practices such as individual-tree selection or a commercial thinning (Smith 1981). The keys to grapevine control are herbicides or canopy shading. Herbicides usually are highly successful in killing vines. Likewise, since the intolerant grapevines need light, shade from the overstory canopy also effectively controls grapevines especially stump sprouts.

Herbicides

Herbicides are often used to control wild grapevines and some are very effective. Presently, the best grapevine herbicide treatments are those applied to the foliage or at the base of the vine trunks. However, grapevine foliage is often beyond reach of mistblowers, and aerial application is not justified because there is no available herbicide selective for grapevines alone. Therefore, an herbicide treatment such as basal spraying the root collar and base of the vine is the more realistic application technique (Fig. 3). In many instances, a recommended herbicide treatment for individual grapevines allows forest managers to choose the number of grapevines to treat. Hamel (1983) lists herbicide treatments to control grapevine growth.

Figure 3.—Basal spraying grapevines with herbicides.

Several herbicides, treatment techniques, and results that have been used for grapevine control by the USDA Forest Service in cooperation with Dow Chemical Company,[1] Monsanto Company, Monongahela National Forest, Jefferson National Forest, and West Virginia Department of Natural Resources follow:

1. Weedone 170 (2,4-D; 2,4-DP)
   a. Mixed herbicide with fuel oil following the label instructions and applied as a basal spray to the base and lower 12 to 18 inches of uncut stems in mid-April, mid-August, mid-September and early March.

   b. Mixed herbicide with fuel oil following the label instructions and applied as a basal spray to cut grapevine stumps and surfaces in mid-September (stumps not bleeding sap).

Results

Grapevines are readily susceptible to 2,4-D herbicides in fuel oil when applied as a basal spray to the base and lower 12 to 18 inches of an uncut vine. Applying herbicides in fuel oil to the stem and cut surface of the grapevine was also successful in killing vines when applied in mid-September. For best results, both vine ends of a layered grapevine should be treated (Fig. 4) when a clearcutting practice is planned within 4 years after the herbicide treatment.

2. 2,4,5-T
   Herbicide mixed in fuel oil following the label instructions and applied as a basal spray to the base of uncut grapevine stems and 12 to 18 inches of lower stem. Herbicide applied to cut grapevine stumps and surfaces in mid-September (stumps not bleeding sap).

Results

Currently, 2,4,5-T cannot be recommended, but the chemical was very effective.

3. Tordon 101; 101R
   Tordon 101 mixed as a 50 percent solution of chemical and water and applied as a basal spray to cut grapevine stump surfaces in April (stumps bleeding sap).

   Tordon 101R applied undiluted as a basal spray to cut surfaces of grapevine stumps in early March and mid-September (stumps not bleeding sap).

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Figure 4.—Basal spraying both ends of a layered grapevine.

Results

Tordon 101R applied to the cut surface of a grapevine stump during early March and mid-September effectively killed grapevines. Tordon 101 applied in April did not consistently kill vines.

4. Roundup (Glyphosate)
   Roundup mixed as a 20 percent solution of chemical and water and applied as a basal spray to the cut surface of grapevine stumps in early March (stumps not bleeding sap), mid-August (stumps bleeding sap), and mid-September (stumps not bleeding sap).

Results

Roundup effectively killed the grapevines in early March and mid-September, but results were poor in mid-August.

5. Frill technique
   Roundup, Weedone 170, Tordon 101R, and 2,4,5-T were applied using a frill technique. Herbicides were applied only to the frill cut using the oil and water herbicide solutions mentioned. This frill application was done in mid-September (vines not bleeding sap).

Results

Frilling grapevines and treating the frills with herbicides was not effective.

6. Mistblowing technique
   Grapevine foliage was mistblown with 2,4-D and Tordon 101 (Smith 1977) and Tordon 10K pellets (80 lbs per acre) were applied to grapevine arbor areas. All herbicides were applied in mid-July.

Results

Ground mistblowing of the grapevine foliage with 2,4-D and Tordon 10K was effective but limited to contact with foliage. Aerial spraying would be better, but no herbicide is selective for grapevines only. Therefore, other woody vegetation would be killed also. Tordon 10K pellets were successful in killing the grapevines, but other nearby vegetation was killed too.

Finally, in a hydrology study on the Fernow Experimental Forest, herbicides were applied to a 60-acre area periodically throughout the growing season for 7 years. The objective was to kill all vegetation for the 7-year period. Several different kinds of herbicides were used (primarily 2,4,5-T; 2,4-D; Dalapon) (Kochenderfer and Wendel 1983). All grapevine stems were killed during the herbicide treatment. After 7 years, the herbicide application was stopped and the stand was allowed to regrow naturally. Initially, the vegetation development was sparse, but 13 years after the last herbicide treatment, seedling grapevines are in the tree crowns of many trees in the 60-acre stand.

To summarize, herbicides kill grapevines and minimize grapevine sprouting, but herbicide treatments applied before an even-age cutting practice will not control seedling-origin vines that germinate after cutting. The success of spraying vine stumps seems to vary with the time of application and success of stump spraying seems to be related to the occurrence of stump bleeding. The tests were done in August, mid-September, early March, and April. Profuse bleeding occurred during the August and April stump treatments. No bleeding was observed at the September or March treatments. Success in killing vines was best during mid-September and early March.

Grapevine Arbors

In stands where grapevines are found, openings often develop in the crown canopy. In these openings, the vines become matted, overtop the trees, and develop an entanglement that primarily is dominated by grapevines. We call these open areas wild grapevine arbors or grapevine clumps (Fig. 5). To my knowledge, there is no practical way to eliminate grapevine arbors. However, grapevines in the trees bordering the openings can be cut to keep the arbor from enlarging. If the grapevine arbors are small enough, the crown canopy from the overstory border trees may eventually close, thus shading the grapevines. In large arbors, crown encroachment from border trees will not occur. Generally, in established grapevine arbors, it is not possible to grow quality hardwood timber for many years.

No doubt it is difficult to control the growth of grapevines within an arbor by using existing techniques. Practical herbicide applications will not prevent the emergence of grape seedlings, and cutting the vines will simply stimulate sprouting. Where the forest management policy is to maintain some grapevines for wildlife purposes, arbors seem to be the logical places to grow vines while the rest of the stand is subject to grapevine control treatments. However, even after designating a desired number of arbors, additional arbors may be present.

Figure 5.—Grapevines dominating the stands—a wild grapevine arbor.

Stand Silvicultural Treatments

Mature Stands—Uneven-age Management (other partial cuts)

Normally, partial cuts such as individual-tree selection, improvement cuts, and some diameter limits result in residual stands with considerable shading of the understory. Grapevines do not grow well under dense shading. Grapevines can be controlled in mature stands by severing or cutting the vines that grow in trees. Vines are severed near ground line before, during, or after logging by using blades, hatchets or chain saws depending on vine size. The cut vine stump will sprout, but the sprouts will die within a few years and barring any drastic overstory removal or natural disaster, the vines will not become a problem in the future.

Large vines are hard to cut, and it may be easier and not as expensive to basal spray the vines with an herbicide-oil solution. Spray the base of the vines and root collar of only those vines attached to the tree crown. No other portion of the vines needs to be treated in this instance. Though we have not basal sprayed vines during all months of the year, we have found that in every instance (early March, mid-April, mid-August, mid-September) the vines died.

Thus, presence of grapevines in mature stands where partial cuts are planned should not present any major control problems to the forest manager. In fact, in some of these stands there may not be enough grapevines to satisfy wildlife management objectives. Thus, depending on forest management objectives, grapevine arbors may need to be established artificially. Seedling-origin grapevines are not a problem under the shade of partially cut stands unless the stands are suddenly opened up due to heavy logging or a windstorm, ice storm, and so on.

Mature Stands—Even-age Management

Although grapevines are easier to control in partially cut, mature stands by simply severing or applying an herbicide basal spray, control is more complicated when any type of even-age harvest cutting practice (clearcuts, shelterwoods) is planned for these stands. Control measures must be considered for both sprout- and seedling-origin vines. A basic assumption is that if grapevines are present before an even-age harvest cut, grapevines will be abundant in the next stand regardless of the preharvest techniques applied to control the grapevines. If time and money permit, the grapevines in the trees could be severed near ground line at least 4 to 5 years before the stand is clearcut. The cut grapevine stumps will produce sprouts, but the sprouts will die within a few years from overstory shading. Of course, the vines could be basal sprayed with an herbicide-oil treatment if desired. Grapevine sprouting should not be a problem after clearcutting, but seed-origin vines will be.

If an even-age harvest cut is planned within 4 years or vine cutting is not permitted, grapevines can be controlled by basal spraying each vine near ground line. It is also advisable to spray the vine layers when a harvest cut is planned within 4 years. The 2,4-D; 2,4-DP herbicide-oil mixture applied as a basal spray on uncut vines and vine layers is an effective grapevine control treatment. However, any herbicide-oil basal spray mixture should work well if grapevines are listed as a target species on the label. After applying the herbicide basal spray treatment, the stand could be harvested. Usually, the new developing stand will still have a serious grapevine problem from seedling-origin vines, and a grapevine control treatment will be necessary after the new stand has developed a closed overstory canopy. This canopy development usually occurs when the codominant trees average 15 feet tall.

When mature stands are scheduled for clearcutting within a few years and forest managers want to control grapevines but do not want to use herbicides, the grapevines should not be cut before, during, or after logging. If the grapevines are cut, the stumps will simply produce more sprouts, and make the situation worse. After clearcutting, some of the uncut vine stems will produce epicormic branches and roots along the stem, a source for sprouting and layering. Thus, when clearcutting, there is no easy, inexpensive way to control the vines in the mature stands before cutting that will eliminate the application of a grapevine control treatment in the regenerated stand. For thinnings, vine control methods are similar to recommendations for partial cuts in mature stands.

Costs to sever vines. Costs to sever grapevines in mature stands were summarized by Smith and Smithson (1975). Since 1975, more data have been collected, and a prediction equation was determined to summarize the data based on 11 areas. However, results varied from the 1975 data. We estimated that mature stands with 10 grapevines per acre required about 0.67 man-hours to sever grapevines while stands with 50 grapevines per acre required about 1.33 man-hours and stands with 200 grapevine stems per acre required about 3.80 man-hours (Table 1). Thus, at $7.00 a man-hour it cost about $9.30 per acre to cut 50 grapevines and $26.60 to cut 200 grapevines. These man-hour estimates include periodic breaks (about 10 minutes per man-hour) for the cutting crew, but travel to and from the

Table 1.—Number of man-hours per acre to cut or basal spray grapevines and gallons of basal spray mixture used per acre (mature stands).

Number treated vines	Man-hours/acre to—		
	Cut[a] vines	Basal spray[b] vines	Herbicide-oil mixture
			Gallons
10	0.67	0.47	0.02
25	.92	.54	.18
50	1.33	.67	.46
100	2.20	.92	1.01
150	3.00	1.17	1.56
200	3.80	1.42	2.11
300	—	1.92	3.21
500	—	2.92	5.41

[a]Man-hour estimates include a 10 minute per man-hour allowance for periodic crew breaks—each crew member cut vines.
[b]Man-hour estimates include a 10 minute per man-hour allowance for periodic breaks—two-man basal spray crew.

grapevine cutting control area and a lunch break were not included in the cost. One factor not evaluated was size of grapevines. It is difficult to cut large vines with hand tools. Sometimes vines are so large that it would be easier to girdle than cut the vine.

Cost to basal spray vines. Costs to basal spray grapevines in mature hardwood stands were also determined. Knowing the number of grapevine stems sprayed per acre and the man-hours required to do the spraying, an equation was developed from the data that accounted for most of the variation (97 percent). Eight treatment areas were evaluated. A 2-man crew did the basal spraying—one crew member sprayed and the other mixed and hauled the herbicide. Slopes ranged from 15 to 35 percent. The treatment areas used to collect this basal spray cost data were small, less than 2 acres. These areas were much smaller than the cut-vine areas of nearly 100 acres. Mixing, hauling, and supplying the basal spray applicator with herbicides could not be adequately evaluated in our basal spray test areas. Thus, basal spraying of vines in this instance is a minimum cost estimate.

Areas with 10 sprayed grapevine stems per acre required about 0.47 man-hours; 50 vines per acre, 0.67 man-hours; and to basal spray 200 grapevine stems per acre, 1.42 man-hours were necessary (Table 1). Man-hours for basal spraying include the spraying of vine layers. Each basal sprayed vine end was counted as a vine though often because of layering the same vine was basal sprayed more than once. Also, if the mature stand is going to be clearcut at least 4 to 5 years after the herbicide treatment, it is not necessary to basal spray the grapevine layers.

Grapevine diameters at ground line for the basal sprayed vines averaged about 1.6 inches and ranged from 0.4 to 5.7 inches with about 25 percent of the vines 2.0 inches in diameter and larger. This vine size is typical in many mature stands regardless of whether the vines were cut or basal sprayed. We used an herbicide-fuel oil mixture that cost $1.47 per gallon ($15.00 per gallon for herbicide, $1.00 per gallon for fuel oil). The basic mixture was 3.5 gallons of herbicide added to 100 gallons of fuel oil. The grapevine stems were basal sprayed using a backpack sprayer and soaking at least the lower 12 to 18 inches of the grapevine stem and the root collar. An average of 1.35 fluid ounces was used per grapevine stem.

Using data in Table 1, we found that the herbicide-fuel oil and labor cost to basal spray 200 grapevine stems (including layers) per acre in a typical second-growth stand was:

1.42 man-hours to basal spray vines @ $7.00 per man-hour	= $ 9.94
2.11 gallons of herbicide mixture @ $1.47 per gallon	= 3.10
	$13.04

Thus, with 200 grapevine stems per acre, it cost a minimum of about $13 an acre to basal spray grapevines in a mature stand. It cost $26.60 per acre to cut 200 vines per acre.

Young Immature Stands—Even-age Management

Of major interest to forest managers is grapevine management in stands after clearcutting practices. If grapevines are present before clearcutting, a grapevine treatment usually will be needed in the regenerated stand during the first 10-year period after clearcutting. In my opinion, any herbicide or mechanical grapevine control measure applied before clearcutting will not eliminate post-clearcutting treatments, though the regenerated stand will have fewer vines as a result of a prelogging treatment. We have not evaluated the influence of the prescribed burning.

Number of grapevines per acre in young immature stands was related to number of man-hours to cut grapevines, number of trees per acre with grapevines present in tree crowns, and percent of the stand with grapevines (Table 2). These data were summarized from surveys of even-aged hardwood stands 10 to 15 years after clearcutting, and the stands had never received a previous grapevine control treatment. Young stands averaging 10 grapevines per acre had about 60 trees per acre with grapevines in the crowns. These 60 trees represent about 3 percent of the stand based on 1,900 stems per acre 1.0 inch dbh and larger. Young stands with 300 grapevines per acre averaged about 480 trees with grapevines in crowns, indicating that about 25 percent of the stand is vulnerable to some reduction in tree quality due to grapevines. Of course, not all trees with grapevines in the crowns will be appreciably damaged and conversely, grapevine damage could be so severe that the tree dies.

It is difficult to determine the minimum amount of vines per acre that creates a significant problem in the reduction of timber quality. However, I suggest that forest managers use the grapevines per acre/grapevines-crown relationship summarized in Table 2. For example, a forest manager may decide that all areas would need grapevine control treatment if more than 5 percent of the trees (40 grapevines per acre) had grapevines in the crowns.

Table 2.—Number of man-hours per acre to cut grapevines and trees with grapevines in the crowns (immature stands).

Grapevines per acre	Man-hours/acre to cut grapevines	Trees with grapevines in crown	
		No./acre	*Percent of stand*[a]
10	0.70	60	3
25	.78	81	4
50	.90	117	6
100	1.15	189	10
150	1.40	262	14
200	1.65	334	18
250	1.90	406	21
300	2.15	478	25
400	2.65	623	33
500	3.15	767	40
600	3.65	912	48
700	4.15	1,056	56
800	4.65	1,200	63
900	5.15	1,345	71
1,000	5.65	1,489	78
1,100	6.15	1,634	86
1,200	6.65	1,778	94

[a]Stand data at the time of the grapevine cutting treatment indicated an average of about 1,900 trees per acre 1.0 inch dbh and larger.

Few options exist when applying grapevine control measures to young stands. Also, because grapevines can quickly become a problem when associated with other factors such as snow and ice, it is important that the grapevine control measures be used in these stands as early as possible. Though herbicides can be used successfully, basal spraying individual vines with herbicides may be more costly than cutting, and herbicide movement in the soil could be more risky to residual trees in the stand. Also, in immature stands, the diameters of the vines are much smaller, there are more vines, and usually vines are cut with one swing. Thus, cutting the grapevines near ground level with a tool such as a Woodsman's Pal or Swedish brush axe is the recommended practice (Fig. 6). This cutting should be done when the codominant trees in the stand are at least 15 feet tall and a well-developed closed canopy is present because shading is the key to successful grapevine control.

Figure 6.—Cutting grapevines in a young immature stand.

The cut grapevine stumps will sprout, but the majority of the sprouts will die within a few years. Usually, the grapevine cutting can be done in the stand less than 10 years after clearcutting. Also, if the codominant trees average 15 feet tall, it is easier for the cutters to walk through the stand to locate and treat the grapevines. It is easy to miss grapevines, and a few inches of snow on the ground aids the crew. When treating the vines, the crew should work across the slope contour and crew members should have overlapping lines. In cutting grapevines under ideal conditions, a good cutting crew will cut about 95 percent of the grapevines.

Cost to sever vines. Time required to sever grapevines in young, immature stands has been determined using regression techniques (Smith and McCay 1979). More data were added since 1979, and all available data were combined (Table 2). A total of 15 young, even-aged stands were used to develop a regression. In the regression, number of grapevines per acre accounted for about 95 percent of the variation. Immature stands with 100 grapevines per acre require about 1.15 man-hours to cut grapevines while stands with 1,000 grapevines per acre should take about 5.65 man-hours to cut the grapevines. Thus, at $7.00 per man-hour, the cost to cut 100 grapevines per acre would be about $8.00 while cutting 1,000 grapevines per acre cost about $39.50 an acre.

Summary and Management Recommendations

In many instances, grapevines are highly desirable, particularly where wildlife is the only concern of the forest manager. However, where quality timber production is the primary objective or where the multiple-use concept is applied, the uncontrolled growth of grapevines often conflicts with growing quality timber and mast-bearing trees. Forest managers need to determine management objectives before deciding what measures to use to control grapevines. For example, if wildlife is the sole management objective, then grapevines may not be controlled or treatments may be used to increase grapevines. Also, the sole wildlife objective could be to grow as many grapevines and produce as many mast-bearing trees as desirable. Grapevine control treatments would be considered in this instance. Where production of quality timber is the sole objective, then an effort could be made to eliminate all grapevines in the managed stand.

However, in practice forest managers usually want to manage stands to produce quality timber and maintain an abundance of wildlife at the same time. A multiple-use management approach is the retention of wild grapevine arbors. The arbor concept provides opportunities for wildlife food and cover while simultaneously allowing the remaining stand to be managed for quality hardwood timber as well as other resource uses.

The research recommendation to manage or control vines in arbors is to confine the vines to the arbors. If grapevines in an arbor are cut, the vines will sprout and thus increase drastically. If the grapevines in an arbor are treated with herbicides, the vines will die, but the grapevine seed in the soil duff will germinate and grapevines will continue to thrive.

Controlling growth of grapevines where overstory shading is present involves cutting the vines and/or spraying them with herbicides. Because grapevines are intolerant of shade, severing the vines is usually an effective control. Recommended guidelines for controlling grapevine development for given stands and silvicultural management situations are as follows:

1. Grapevine control practices should be applied in areas with an oak site index 60 or higher.

2. *Mature Stands Using Even-Age Silviculture and Management Practices*

   a. Stands to be harvested within 3 years. Retain wild grapevine arbors.

      Basal spray herbicides (2,4-D; 2,4-DP) on the lower 12 to 18 inches and the root collar of uncut grapevines attached to the tree crowns. Apply herbicide-oil mixture to the layered vines along the ground surface. Do not treat grapevines inside arbors. Also, basal spray grapevines attached to the crowns of trees surrounding the arbor openings.

      If a basal spray herbicide cannot be used, sever grapevines during the late winter, early spring, or fall and spray the cut stump surface with Roundup (20 percent solution) or Tordon 101R. Herbicides should be applied when sap is not bleeding from the cut stump.

   b. Stands to be harvested in 4 or more years. Retain wild grapevine arbors.

      For the remaining grapevines in the area, sever all vines near ground line that are attached to the tree crowns other than those inside the arbors. Also, cut grapevines in the crowns of trees surrounding the arbor openings.

      Herbicide applications as suggested for stands where a harvest cut is planned in 4 or more years are effective control treatments; however, it is not necessary to apply herbicide to vine layers.

3. *Young Immature Stands Using Even-Age Silviculture and Management Practices*

If a forest manager decided to apply a grapevine control treatment to a stand when 5 percent of the trees had grapevines in the crowns (managers can use any percent so desired as discussed in Table 2), then about 40 grapevines per acre would indicate a grapevine control treatment is needed. Thus, using 40 grapevines per acre, the following would be applicable.

a. Commercial-size stands to be thinned.
   Stands with less than 40 grapevines per acre.
   Retain wild grapevine arbors.
   Do not apply grapevine control methods.

   Stands with 40 or more grapevines per acre.
   Retain wild grapevine arbors.
   Cut all grapevines near ground line that are attached to the tree crown other than those vines inside the arbor. Herbicide applications are not necessary because overstory crown shading will control the sprouting grapevine stumps.

b. Precommercial-size stands.
   Stands with less than 40 grapevines per acre.
   Retain wild grapevine arbors.
   Do not apply grapevine control methods.

   Stands with 40 or more grapevines per acre.
   Delay any grapevine control treatments until the stands have developed a fully closed canopy. Shading is the key to controlling the grapevines. Usually grapevine control treatment can begin when the codominant trees in the fully stocked stand are at least 15 feet tall, approximately 8 to 10 years after the harvest cut—when one can easily walk under the tree crowns.

   Retain wild grapevine arbors.
   Cut all grapevines near ground line that are attached to the tree crowns other than those vines inside the arbors. Also, sever all grapevines in the crowns of trees surrounding the arbor openings. Try to apply the grapevine cutting control measures during the dormant season and ideally with a few inches of snow on the ground. If done at this time, a good cutting crew will miss only about 5 percent of the vines.

   Application of herbicides is not necessary because crown shading will control the vines.

c. Grapevines in stand, but no distinguishable arbor.
   Stands with 40 grapevines per acre or less.
   Apply no grapevine control measures.

   Stands with 40 or more grapevines per acre.
   Select concentrated groups of grapevines in tree crowns representing a desired percent of the area (example 5 percent). Do not treat these selected vines during application of a grapevine control treatment to the rest of the stand. Trees could be felled to speed up arbor development.

   Cut all remaining grapevines in the stand near ground line where the vines are attached to the tree crown using the cutting technique described in 3b. Herbicides are effective but not necessary.

d. Crop-tree release.
   In precommercial-size stands with grapevine problems, delay crop-tree release about 4 to 5 years after a grapevine control treatment. Shading kills the grapevine stump sprouts and if a heavy release and grapevine control cutting are done simultaneously, grapevine sprouting could be stimulated by the treatment. This recommendation also depends on the average height of the trees in the stand or whether herbicides are used. As trees become taller and shading increases, the delay of releasing crop trees after a grapevine treatment becomes less important. Also, herbicides could be applied to the grapevines during a crop-tree release treatment; however, an herbicide control treatment could risk mortality to some of the crop trees.

4. *Uneven-Age Silviculture and Management Practices*

   a. Individual-tree selection and other partial cuts.
      Retain wild grapevine arbors.
      Because tolerant species will eventually dominate the stand, grapevine control measures are optional and can be examined on a stand-by-stand basis. Other than in the arbors, once the grapevines are cut near ground level in a stand managed with the selection cutting practice, the vines will not return.

b. Group selection

Zero to 3 years before the harvest cut.

Retain wild grapevine arbors within the stand.

For the proposed group openings, basal spray herbicides on the lower 12 to 18 inches of the grapevine stem and root collar on uncut grapevines attached to the tree crowns before cutting. Also, apply herbicide to the layered vines along the ground surface. Do not treat grapevines inside arbors. Basal spraying with 2,4-D; 2,4-DP in oil provides good results. If a basal spray cannot be used, cut grapevines and spray the cut stump surface with Roundup (20-percent solution) or Tordon 101R as purchased. Roundup and Tordon 101R are effective primarily when the grapevines are not bleeding sap (late winter, early spring, fall).

For the remaining stand, sever or basal spray the grapevines.

Four or more years before the harvest cut.

Retain wild grapevine arbors.

For the remaining stand including any designated group openings, sever or basal spray vines near ground line that are attached to the tree crowns. This includes all vines in tree crowns other than those trees inside grapevine arbors.

These guidelines will help the forest managers make decisions on controlling growth of wild grapevines and at the same time satisfy wildlife and timber objectives in a managed stand or forest.

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Caution

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Environmental Protection Agency, consult your local forest pathologist, county agricultural agent, or State Extension specialist to be sure the intended use is still registered.

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Grapevines (*Vitis* spp.) are becoming a major problem to forest managers in the Appalachians, especially when clearcutting is done on highly productive hardwood sites. Where present, grapevines can reduce tree quality and growth, and eventually kill the tree. Silvical characteristics of grapevines are discussed as background for grapevine control. Forest management guidelines are given for controlling growth of grapevines.

441 6 176.1 (*Vitis;* Central Appalachian hardwoods)

Keywords: grapevines, control guidelines, silvical characteristics

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984—705-029/522

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United States
Department of
Agriculture

Forest Service

**Northeastern Forest
Experiment Station**

Research Paper
NE-549

1984

Black Cherry Site Index Curves for the Allegheny Plateau

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Manuscript received for
publication 1 May 1984.

Abstract

Black cherry site index curves were developed for the Allegheny Plateau in northwestern Pennsylvania. They show for this region that height rises less sharply prior to the index age and is maintained for a longer period thereafter than described by existing curves. An equation to predict site index from height and age is furnished to allow the use of these curves in computer processing. For field use, a table of site indexes by 2-foot heights and 2-year ages is provided.

Introduction

For many years the only available site index curves for black cherry (*Prunus serotina* Ehrh.) were those developed in 1937 by S. E. Defler,[1] and later published by the USDA Forest Service (Hampf 1965). These were harmonized curves made from height and age measurements taken in 38 stands growing in south-central New York and northwestern Pennsylvania. These curves have been used extensively.

More recently, a second set of black cherry site index curves was developed for the northern Lake States region (Carmean 1978). These are polymorphic curves made from stem analyses of 126 trees located on 42 plots. These curves generally agree with the Defler curves below the index age, but show considerable departure above. Since the entire data set used to develop the Carmean curves came from the extreme northwestern commercial range of black cherry, it may not be strictly applicable to other geographic regions that differ in climate, soils, and in black cherry growth rates.

Black cherry is one of the most important and most valuable eastern hardwoods. It is found in commercial quantities and attains its best growth and development on the Allegheny Plateau of western Pennsylvania and New York and southward throughout the Allegheny Mountains. Yet the accuracy with which existing site index curves describe black cherry height/age relationships within this region remains undetermined. Therefore, the purpose of this study was to construct a set of black cherry site index curves applicable to sites on the Allegheny Plateau of western Pennsylvania and New York, and to compare these curves with those that already exist.

[1]Defler, Sam E. Black cherry characteristics, germination, growth, and yield. Unpublished M.S. thesis. New York State College of Forestry; 1937.

Procedures

Six fully stocked Allegheny hardwood stands were selected for sampling. The sampled stands were even-aged second growth, about 70 years old, free from cutting, and located on the Allegheny Plateau in northwestern Pennsylvania. These stands originated after heavy clearcutting early in the century, and now contain 30 to 50 percent black cherry in admixture with white ash (*Fraxinus americana* L.), red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marsh.), and beech (*Faqus grandifolia* Ehrh.). The prevailing cool and moist climate of the area is characterized by a 120-day frost-free period and 44 inches of well-distributed precipitation, and is typical of conditions where black cherry attains its best development.

The six sites included soils that ranged in drainage from well drained to somewhat poorly drained, and in soil texture from loam to silty clay loam. All were residual soils, having developed in place from the underlaying parent material. The effective rooting depth was generally less than 3 feet, being limited by a fragipan, perched water table, or compact stony layers above bedrock. Soils included the Cookport, Clymer, Hazelton, and Wharton series, which are representative and important forest soils in the region. Only the very wettest and most poorly drained soils where black cherry is seldom found and grows poorly were not sampled.

A total of 39 sample trees growing within the six areas were felled and dissected. All trees were dominants or codominants that had no serious stem deformities, and they showed no evidence of suppression or disease. Site index at age 50 of the sampled trees ranged from 56 to 82 feet.

Felled trees were sectioned at 5-foot intervals for their entire length. At each dissection point, the height above ground was recorded and a 1-inch-thick disk removed for age determinations in the laboratory.

Height and age data were adjusted to compensate for dissections not coinciding with the maximum height attained for a particular age, and for differences in the number of years required for seedlings to reach breast height. Because actual tree heights usually are greater than heights of the dissection points, heights were adjusted upward by adding half of the average annual height growth to the height of each dissection point (Carmean 1972). To avoid variation in the time required for stands to reach 4.5 feet, a constant 4 years were added to age at breast height to obtain total age.

The site index curves were constructed by a technique similar to one described by McQuilkin (1974). First, regressions of the form $Y = a + bX - cX^2$ were fitted to the adjusted height (Y) and age (X) of each sample tree. All regressions were significant ($P \leq .01$) and had R^2 exceeding 0.99. From these regressions, the actual site index (height at age 50) and the corresponding heights attained at 10, 20, 30, 40, 50, 60, 70, and 80 years were obtained for each of the 39 trees. Next, these data were used to develop linear regressions with site index as the dependent variable and height as the independent variable for each of the eight age classes. These regressions were then used to determine the tree heights at 10-year age intervals that predicted site indexes of 40, 50, 60, 70, 80, 90, and 100. Finally, these heights and ages were used to plot each of the 10-foot site index curves from 40 to 100. The ability of these curves to describe height/age relationships was checked by comparing heights obtained from the curves with the actual heights attained by the original 39 trees, but no evaluation was made with an independent sample.

Results

The black cherry site index curves derived in this study are given in Figure 1. They show substantially different height/age patterns than described in the original curves by Defler[1] and by the curves developed for the Lake States by Carmean (1978). In both sets of existing curves, height rises sharply before the index age and then falls off quickly after the age of 50 years. By contrast, second-growth cherry in northwestern Pennsylvania has slower early growth and more sustained height growth after the index age. These differences in curve form mean that using the other curves locally will result in lower than actual site indexes for stands between the ages of 20 and 50 years, and higher than actual site indexes in stands older than 50 years. These deviations are large, underestimating by as much as 15 to 16 site index points in very young stands (age 20) to overestimates of 10 to 15 site index points at age 80 (Table 1).

The new curves appear to closely track black cherry height/age patterns in this area, as evidenced by small mean departures between the original 39 sample trees and the composite site index curves (Table 2). Though the accuracy of the curves has not been verified with independent data, we nevertheless believe that the curves can be used with confidence since the sample trees used for their development and the sites upon which the sample trees grew were highly representative of the region.

To enable the use of the curves with electronic data processing, an equation was developed to predict site index from height and age. The equation is:

$$\text{Site Index} = 71.558 + 1.437(\text{height}) - 2.353(\text{age}) + 0.016(\text{age}^2) - 0.007(\text{height} \times \text{age})$$

Each of the four variables are significant ($P \leq .01$). The equation has an R^2 of 0.993 and a standard error of estimate equal to 1.78 feet.

Table 1.--Comparative site indexes at several heights and ages using the present curves, Defler's curves, and Carmean's curves (deviations from present curves in parentheses)

Height (feet)	Age 20			Age 30			Age 40			Age 60			Age 70			Age 80		
	Present curves	Defler	Carmean	Present curves	Defler	Carmean	Present curves	Defler	Carmean	Present curves	Defler	Carmean	Present curves	Defler	Carmean	Present curves	Defler	Carmean
20	55	—[a]	39(−16)															
30	70	55(−15)	59(−11)	52	40(−12)	44(−8)												
40	84	73(−11)	76(−8)	65	56(−9)	57(−8)	51	46(−5)	47(−4)									
50	100	91(−9)	—	78	70(−8)	69(−9)	62	57(−5)	58(−4)	42								
60				90	83(−7)	80(−10)	73	68(−5)	68(−5)	50	46(+4)	44(+2)						
70				102	98(−4)	—	84	80(−4)	78(−6)	59	55(−5)	54(+4)	44	51(+7)	48(+4)	40	48(+8)	44(+4)
80							94	91(−3)	—	69	64(−5)	64(+5)	52	60(+8)	58(+6)	47	57(+10)	54(+7)
90										78	73(−4)	74(+5)	60	68(+8)	69(+9)	55	65(+10)	65(+10)
100										88	82(−4)	—	70	77(+7)	81(+11)	63	73(+10)	78(+15)
110										97	91(−3)	—	79	85(+6)	—	73	81(+8)	—
120											100(−3)	—	88	94(+6)	—	82	89(+7)	—
													98	102(+4)	—	92	98(+6)	—

[a]Site indexes are beyond those given by the height/age curves.

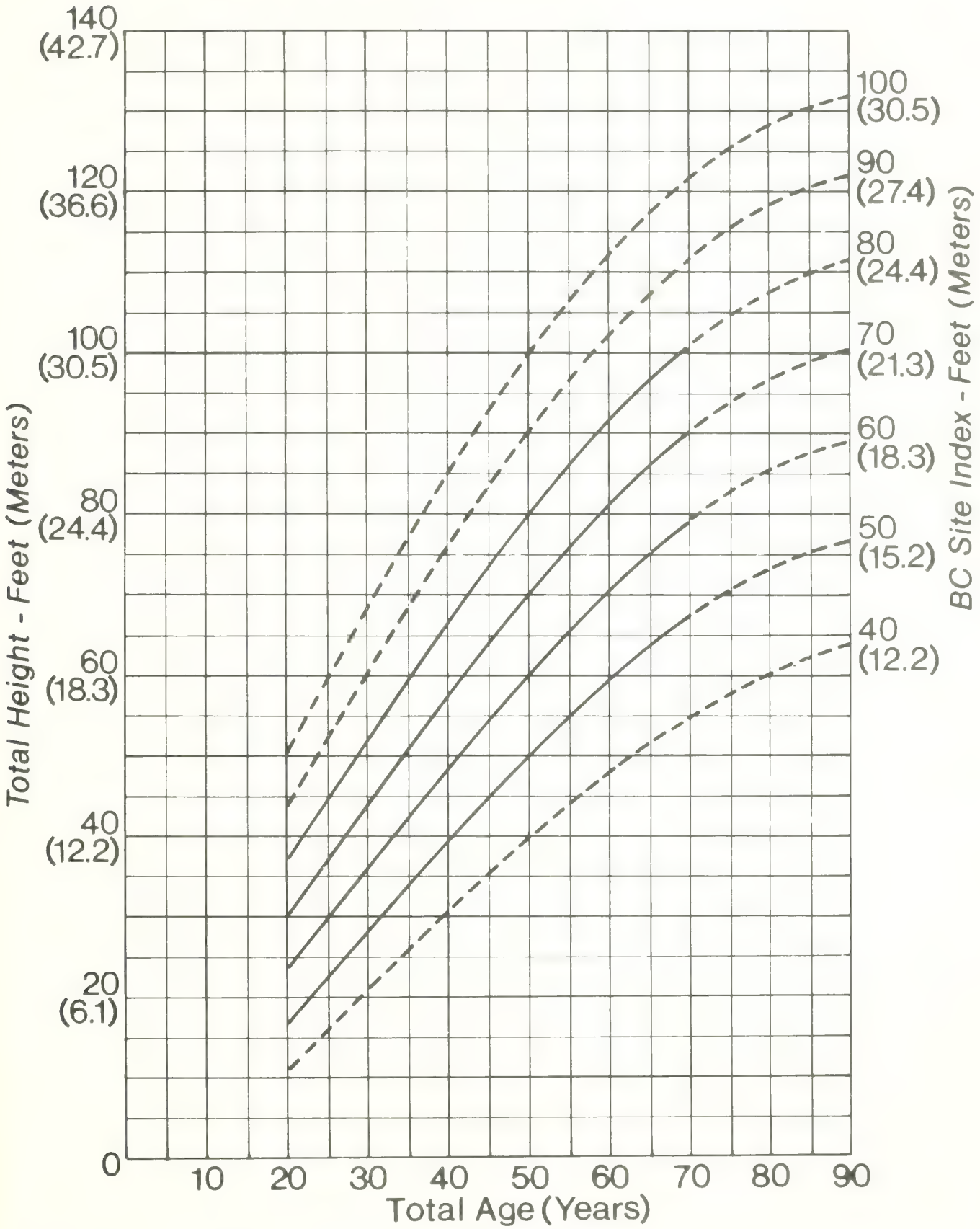

Figure 1.—Black cherry site index curves for the Allegheny Plateau. Four years should be added to breast-height age to obtain total age. Dashed lines are beyond observed data.

Table 2.—Departure of the new site index curves from actual height/age patterns of the 39 sample trees (site index curve height + actual height)

Age	Mean departure	Maximum negative departure	Maximum positive departure
		Feet	
20	−0.3	−3	+4
30	+0.1	−2	+4
40	+0.2	−1	+3
50	0	0	0
60	−0.4	−4	+2
70	−1.2	−9	+4

To simplify the use of the site index curves in the field, and to eliminate the need for interpolating between the 10-foot site classes shown in Figure 1, the equation was used to produce a table of site indexes by 2-foot heights and 2-year age classes (Table 3). The table can be used in lieu of the curves by simply picking out the site index that corresponds to the appropriate height and stand age.

Tabular values computed with the equation and given in Table 3 are similar but not identical to those obtained directly from the curves (Fig. 1). For example, at the index age of 50, tabular site indexes are about 2 feet less than those from the curves at site index 50 and below, and are about 2 feet higher than indicated by the curves at site index 90 and above. Nevertheless, nearly all values in the table are within ± 2 feet of the site indexes obtained directly from the curves. This is sufficient for field use.

Discussion

The curves developed in this study apply to stands that have not been damaged by major ice and glaze storms, and to those which have remained relatively well stocked throughout their life. Measurements from stands where extensive stem breakage has occurred, such as that associated with the glaze storms of 1936 and 1950 (Hough 1959), will result in abnormally low site indexes. Many stands on the Allegheny Plateau have experienced this type of stem breakage, so care must be exercised in selecting sites that are free of such disturbance.

Low estimates of site index also are likely if the present curves are applied to stands that are sparsely stocked, such as orchard stands and those that may have existed many years at less than 40 to 50 percent relative density. This will occur simply because black cherry requires strong lateral competition to develop straight boles and to maintain normal rates of height growth.

Finally, the best estimates of site index will be obtained if breast height age plus 4 years is used as a measure of total age rather than the actual age since stand establishment. This will minimize the effect of variables, such as deer browsing, that are not site related but that have a major impact on early height growth. The use of actual age, such as that determined from stand records or low stumps, will result in lower than actual site indexes where it has taken more than 4 years for the stand to reach breast height.

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Table 3.—Black cherry site index estimates by 2-foot heights and 2-year ages.

Stand age (years)	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
20	52	54	57	59	62	65	67	70	72	75	78	80	83	85	88	91	93	96	98	101																														
22	48	51	53	56	58	61	63	66	69	71	74	76	79	81	84	87	89	92	94	97	99																													
24	45	47	50	52	55	57	60	62	65	67	70	73	75	78	80	83	85	88	90	93	95	98	100																											
26	41	44	46	49	51	54	56	59	61	64	66	69	71	74	76	79	81	84	86	89	91	94	96	99																										
28	38	41	43	46	48	51	53	55	58	60	63	65	68	70	73	75	78	80	83	85	88	90	93	95	98																								
30		38	40	42	45	47	50	52	55	57	60	62	64	67	69	72	74	77	79	82	84	86	89	91	94	96	99																						
32			37	39	42	44	47	49	52	54	56	59	61	64	66	68	71	73	76	78	81	83	85	88	90	93	95	97	100																				
34				37	39	41	44	46	48	51	53	56	58	60	63	65	68	70	72	75	77	80	82	84	87	89	92	94	96	101																			
36						39	41	43	46	48	50	53	55	57	60	62	64	67	69	72	74	76	79	81	83	86	88	90	93	95	98	100																		
38							38	40	43	45	47	50	52	54	57	59	61	64	66	68	71	73	75	78	80	82	85	87	89	92	94	96	99																	
40								38	40	42	45	47	49	52	54	56	59	61	63	66	68	70	72	75	77	79	82	84	86	89	91	93	95	98																
42									38	40	42	45	47	49	51	54	56	58	60	63	65	67	70	72	74	76	79	81	83	85	88	90	92	95	97	99														
44										38	40	42	44	47	49	51	53	56	58	60	62	65	67	69	71	74	76	78	80	82	85	87	89	91	94	96	98	100												
46											37	40	42	44	46	49	51	53	55	57	60	62	64	66	69	71	73	75	77	80	82	84	86	89	91	93	95	97	100											
48												37	40	42	44	46	48	51	53	55	57	59	62	64	66	68	70	73	75	77	79	81	83	86	88	90	92	94	97	99									
50													38	40	42	44	46	48	51	53	55	57	59	61	64	66	68	70	72	74	77	79	81	83	85	87	89	92	94	96	98	100						
52														38	40	42	44	46	48	51	53	55	57	59	61	63	65	68	70	72	74	76	78	80	83	85	87	89	91	93	95	97	100					
54															38	40	42	44	46	48	51	53	55	57	59	61	63	65	67	70	72	74	76	78	80	82	84	86	88	91	93	95	97	99					
56																38	40	42	45	47	49	51	53	55	57	59	61	63	65	67	69	71	74	76	78	80	82	84	86	88	90	92	94	96	98				
58																37	39	41	43	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	76	78	80	82	84	86	88	90	92	94	96	98			
60																	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	82	84	86	88	90	92	94	96	98	100	
62																		38	40	42	44	46	48	50	52	54	56	58	60	62	64	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97
64																			38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	77	79	81	83	85	87	89	91	93	95
66																				39	41	43	45	47	49	51	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	81	83	85	87	89	91	93
68																					40	42	44	45	47	49	51	53	55	57	59	61	63	64	66	68	70	72	74	76	78	80	82	84	85	87	89	91
70																						41	42	44	46	48	50	52	54	56	57	59	61	63	65	67	69	71	72	74	76	78	80	82	84	86	87	89
72																							41	43	45	47	49	51	53	54	56	58	60	62	64	65	67	69	71	73	75	77	78	80	82	84	86	88
74																								42	44	46	48	50	52	53	55	57	59	61	62	64	66	68	70	72	73	75	77	79	81	82	84	86
76																									43	45	47	49	51	52	54	56	58	60	61	63	65	67	69	70	72	74	76	78	79	81	83	85
78																										45	46	48	50	52	53	55	57	59	60	62	64	66	68	69	71	73	75	76	78	80	82	83
80																											46	48	49	51	53	54	56	58	60	61	63	65	67	68	70	72	74	75	77	79	81	82
82																												47	49	50	52	54	56	57	59	61	62	64	66	68	69	71	73	74	76	78	80	81
84																												47	48	50	52	53	55	57	58	60	62	64	65	67	69	70	72	74	75	77	79	80
86																													48	50	51	53	55	56	58	60	61	63	65	66	68	70	71	73	75	76	78	80
88																													48	50	51	53	55	56	58	59	61	63	64	66	68	69	71	72	74	76	77	79
90																													48	50	51	53	54	56	58	59	61	62	64	66	67	69	70	72	74	75	77	78

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Black cherry site index curves were developed for the Allegheny Plateau in northwestern Pennsylvania. They show for this region that height rises less sharply prior to the index age and is maintained for a longer period thereafter than described by existing curves. An equation to predict site index from height and age is furnished to allow the use of these curves in computer processing. For field use, a table of site indexes by 2-foot heights and 2-year ages is provided.

ODC 541:561.1

Keywords: *Prunus serotina;* site index curves; height growth

U.S. GOVERNMENT PRINTING OFFICE: 1984—705-029/529

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United States
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Agriculture

Forest Service

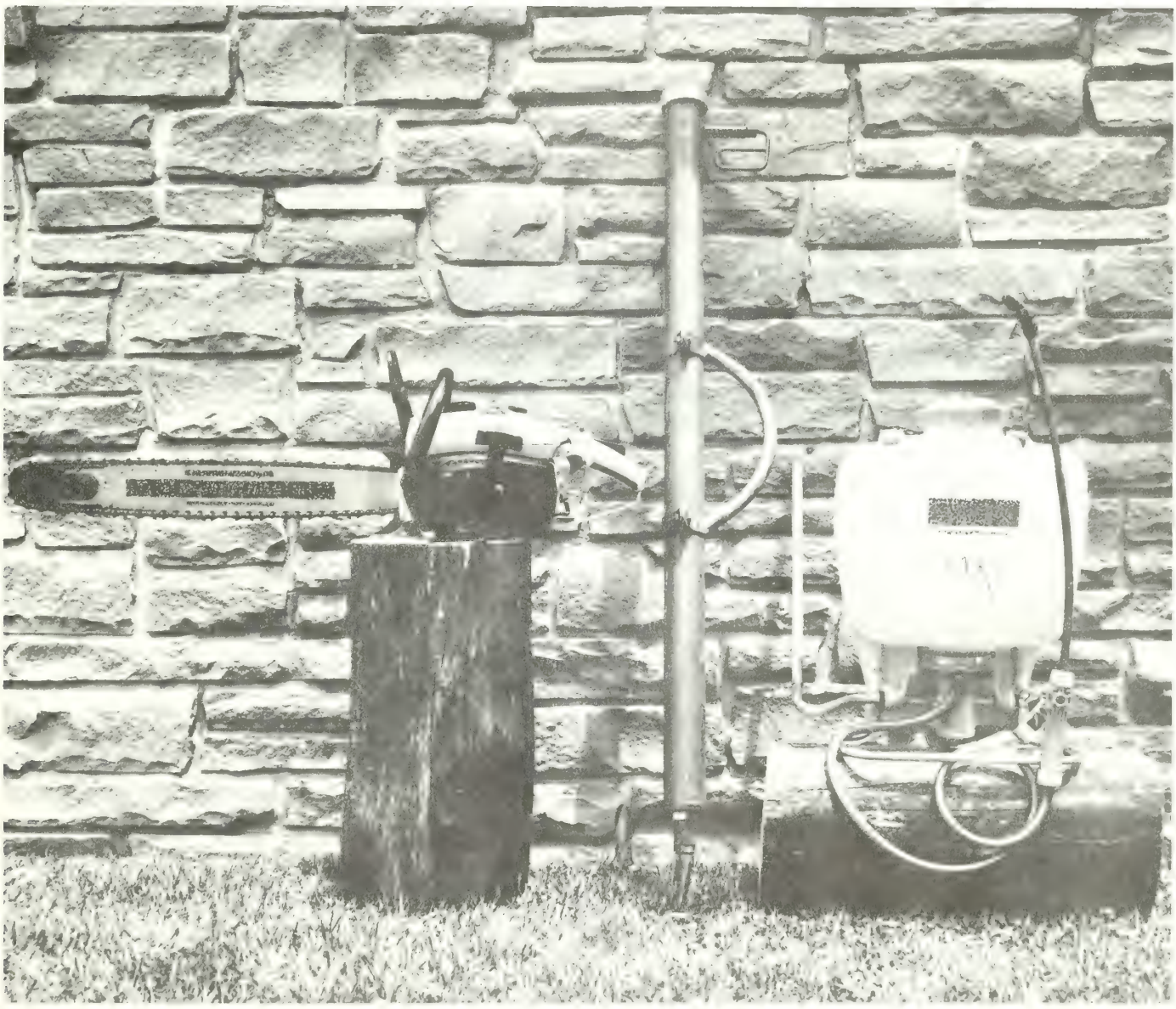
**Northeastern Forest
Experiment Station**

Research
Paper NE-550

1984

Releasing Young Hardwood Crop Trees—Use of a Chain Saw Costs Less Than Herbicides

Gary W. Miller



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Manuscript received for
publication 16 April 1984.

Abstract

A crown-touching release of 12-year-old black cherry and yellow-poplar crop trees on a good site required removing an average of 14 trees for every crop tree. An average of 80 crop trees per acre was left free-to-grow with an average growing space of 4.7 feet on all sides of the crown. Basal spraying cost $0.80 per crop tree, stem injecting cost $0.61 per crop tree, and chain saw felling cost $0.42 per crop tree. Cost indicators for each release method and suggestions for cost savings are provided.

Introduction

Forest managers contemplating crop-tree release need to consider at least three factors that determine the effectiveness and efficiency of release treatments: First, the criteria for recognizing potentially responsive hardwood stands and individual crop trees within those stands; second, the degree of release needed to increase growth of selected trees; and third, the application of release—applying the desired treatment at the lowest possible cost.

In support of the first factor, recent research indicates that Appalachian hardwood crop trees had a significant d.b.h. growth response to release when the seedling and sprout origin codominant trees in the stand were at least 25 feet tall (Lamson 1983, Smith and Lamson 1983). Apparently, until the stand is about 25 feet tall, codominant trees have not competed for crown position long enough to permit natural selection of superior trees. In shorter stands, crown classes are not stable, often resulting in crown-class regression and inconsistent growth responses following release (Trimble 1973, 1974, Smith 1979).

The degree of release is also important. Positive results were obtained when seedling origin crop trees were released by cutting all competing trees touching or within a vertical projection of the crop-tree crown—a crown-touching release (Smith and Lamson 1983). Sprout origin crop trees had a significant d.b.h. growth response when released to a free-to-grow position by cutting all but one or two stems per clump (Lamson 1983). Bole releases, where stems within a specified distance of the crop-tree bole are eliminated, do not always provide a complete crown release for some species. It is important, therefore, to concentrate on the crop-tree crown when applying the release treatment.

This paper summarizes cost information for release. The costs of mechanical and chemical treatments for releasing crop trees in a 12-year-old Appalachian hardwood stand are compared. The cost information reported here was recorded during a crown-touching release of crop trees measuring 30 to 35 feet tall.

Study Methods

Two options exist for eliminating unwanted trees when releasing young hardwoods. Competing trees can be chemically treated by either stem injection or basal spraying with an appropriate herbicide, or they can be cut mechanically. In this study, crop trees were released by injecting, basal spraying, and chain saw felling unwanted stems to define the least-cost method of release.

Cost data were collected in a 12-year-old Appalachian hardwood stand that contained about 2,700 stems per acre, totalling 77 square feet of basal area per acre in trees 1.0-inch d.b.h. and larger (Fig. 1). More than 80 percent of the trees were less than 3.0-inches d.b.h. Most of the dominant and codominant stems were seedling-origin black cherry, *Prunus serotina* Ehrh., and yellow-poplar, *Liriodendron tulipifera* L. Some red oak, *Quercus rubra* L., sprout clumps were also present.

Figure 1.—Crop trees were severely crowded before release.

We selected 80 crop trees per acre based on the following criteria:

- Species—black cherry or yellow-poplar
- Crown class—dominant or codominant
- Origin—seedling preferred
- Stem form—straight stem, few forks
- Vigor—full, healthy crowns, no dead tops

In some instances, other species or sprout origin trees were selected as crop trees because they were the best available tree at the desired location. Cut trees were mostly black cherry, sweet birch, *Betula lenta* L., and red oak sprout clumps.

After crop trees were selected in each study area, all trees (1.0-inch d.b.h. and larger) whose crowns touched or were within a vertical projection of the crop-tree crown were marked with orange paint. An experienced worker then injected all marked trees. To make a direct cost comparison, the same worker went back into the plot and basal sprayed all the marked trees. Finally, the worker felled the marked trees with a chain saw.

During each of the three treatments, an observer recorded the time required to complete the operation, the number of trees treated, and the number of injections required during the injection treatment. The amount of herbicide mix needed to complete each operation was recorded, as were delays associated with each treatment such as fill-ups and rest breaks.

Basal spraying, stem injection, and chain saw felling were compared on two separate plots within the same stand. The first area measured 0.25 acres, the second 0.43 acres. Additional cost data on chain saw felling were collected on two 1-acre plots installed to study the long-term effects of the crown-touching release. A ¼-acre measurement plot within each 1-acre treatment area provided data on individual trees.

Results

Releasing 80 crop trees per acre required removing 1,082 stems per acre, or 14 per crop tree. Following treatment, crop trees were left free-to-grow with an average growing space of 4.7 feet on all sides of the crown. A comparison of basal spraying, stem injection, and chain saw felling indicated that felling eliminated unwanted stems at the lowest cost—about $0.42 per crop tree. Moreover, felling revealed 60 additional competing trees per acre that were not apparent during the basal spraying and injection treatments.

Basal Spraying

An experienced worker using a backpack sprayer treated 309 stems per hour with a 4-percent mixture of 2,4-D ester in oil. The treatment required 3.5 man-hours per acre and 18 gallons of chemical mixture per acre (Table 1). The total treatment cost was $64.00 per acre or $0.80 per crop tree.

Stem Injection

The workers injected an average of 204 trees per hour in the study plots. This treatment required 5.3 man-hours per acre and 1 gallon of chemical solution per acre. The cost of the chemical, a 20 percent solution of glyphosate found to be effective in killing most hardwoods (Wendel and Kochenderfer 1982), was $17.00 per gallon (Table 1). Labor and chemicals combined resulted in a total treatment cost of $48.80 per acre or $0.61 per crop tree.

Chain Saw Felling

The workers felled approximately 260 stems per hour. This method of release required 4.1 man-hours per acre and 3.2 machine hours per acre. The total cost, including labor and the fixed and operating costs of a Pro Mac 800[1] chain saw, was $33.60 per acre or about $0.42 per crop tree.

[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Table 1.—Average time, volume of chemical, and cost per crop tree to apply a crown-touching release in 12-year-old Appalachian hardwood stands

Treatment	Labor[a]		Machine[b]		Chemical		Total cost
	Time	Cost	Time	Cost	Volume	Cost	
	Minutes	*Dollars*	*Minutes*	*Dollars*	*Gallons*	*Dollars*	*Dollars*
Basal spraying	2.6	0.28	—	—	0.23	0.52[c]	0.80
Stem injection	4.0	.44	—	—	.01	.17[d]	.61
Chain saw felling	3.1	.34	2.4	0.08	—	—	.42

[a] Labor cost: $5.00 + 31 percent fringe benefits = $6.55 per hour.
[b] Machine cost: $2.12 per productive hour for chain saw, negligible for other treatments.
[c] Chemical cost: 4 percent mixture of 2,4-D ester in oil = $2.26 per gallon.
[d] Chemical cost: 20 percent solution of glyphosate = $17.00 per gallon.

Discussion

The total cost of labor was highest for stem injection. While unwanted stems in the felling and basal spraying operations could be treated from one side, injection required the workers to walk around trees to properly space the injections. The added walking and difficulty of movement through the dense young stand combined to reduce productivity for injection.

Treatment costs can be reduced by selecting fewer crop trees per acre and by eliminating fewer trees per crop tree (Table 2). More than 60 percent of the trees eliminated in accordance with the crown-touching release guidelines were overtopped before treatment. In this study, if overtopped trees had been ignored, the release would have required eliminating only about six trees per crop tree. Chain saw felling, however, would still have been the least-cost method.

What about sprouts from cut stumps? Stump sprouts in clearcuts can attain a height of about 35 feet in 10 years (Wendel 1975, Lamson 1976). Crop trees selected in this study averaged 34 feet at the time of treatment. Assuming released crop trees grow about 2 feet per year (Smith and Lamson 1983, Lamson and Smith 1978), in 10 years the crop trees will be more than 50 feet tall. With crown closure among crop trees inhibiting the height growth of stump sprouts, crop trees should maintain a distinct height advantage over stump sprouts in stands similar to the study area.

Another advantage to chain saw felling is that it assures that all unwanted trees are eliminated. As trees are felled in favor of a selected crop tree, the operator can recognize competing trees at a glance. Because the herbicide treatments leave competitors standing, trees can be missed or left alive, leaving crop trees only partially released. This problem is magnified during the growing season when trees are in full leaf. With chain saw felling, the operator simply continues cutting until light encircles the crop-tree crown, regardless of the season.

Table 2.—Cost of selecting[a] and releasing various numbers of crop trees using three methods of release

Crop trees per acre	Basal spraying	Stem injection	Chain saw felling
	Dollars/Acre		
50	46.97	37.47	27.97
60	56.36	44.96	33.56
70	65.76	52.46	39.16
80	75.15	59.95	44.75

[a]Selecting crop trees in young hardwood stands required about 1 hour for every 47 crop trees selected (Smith and Lamson 1983).

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Caution

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Environmental Protection Agency, consult your local forest pathologist, county agricultural agent, or State Extension specialist to be sure the intended use is still registered.

Miller, Gary W. **Releasing young hardwood crop trees—use of a chain saw costs less than herbicides.** Res. Pap. NE-550. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1984. 5 p.

A crown-touching release of 12-year-old black cherry and yellow-poplar crop trees on a good site required removing an average of 14 trees for every crop tree. An average of 80 crop trees per acre was left free-to-grow with an average growing space of 4.7 feet on all sides of the crown. Basal spraying cost $0.80 per crop tree, stem injecting cost $0.61 per crop tree, and chain saw felling cost $0.42 per crop tree. Recommendations on release methods and suggestions for cost savings are provided.

ODC 242, 231.324, 176.1

Keywords: Thinning, chemical release, costs, Appalachian hardwoods

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984—705-029/530

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United States
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Forest Service

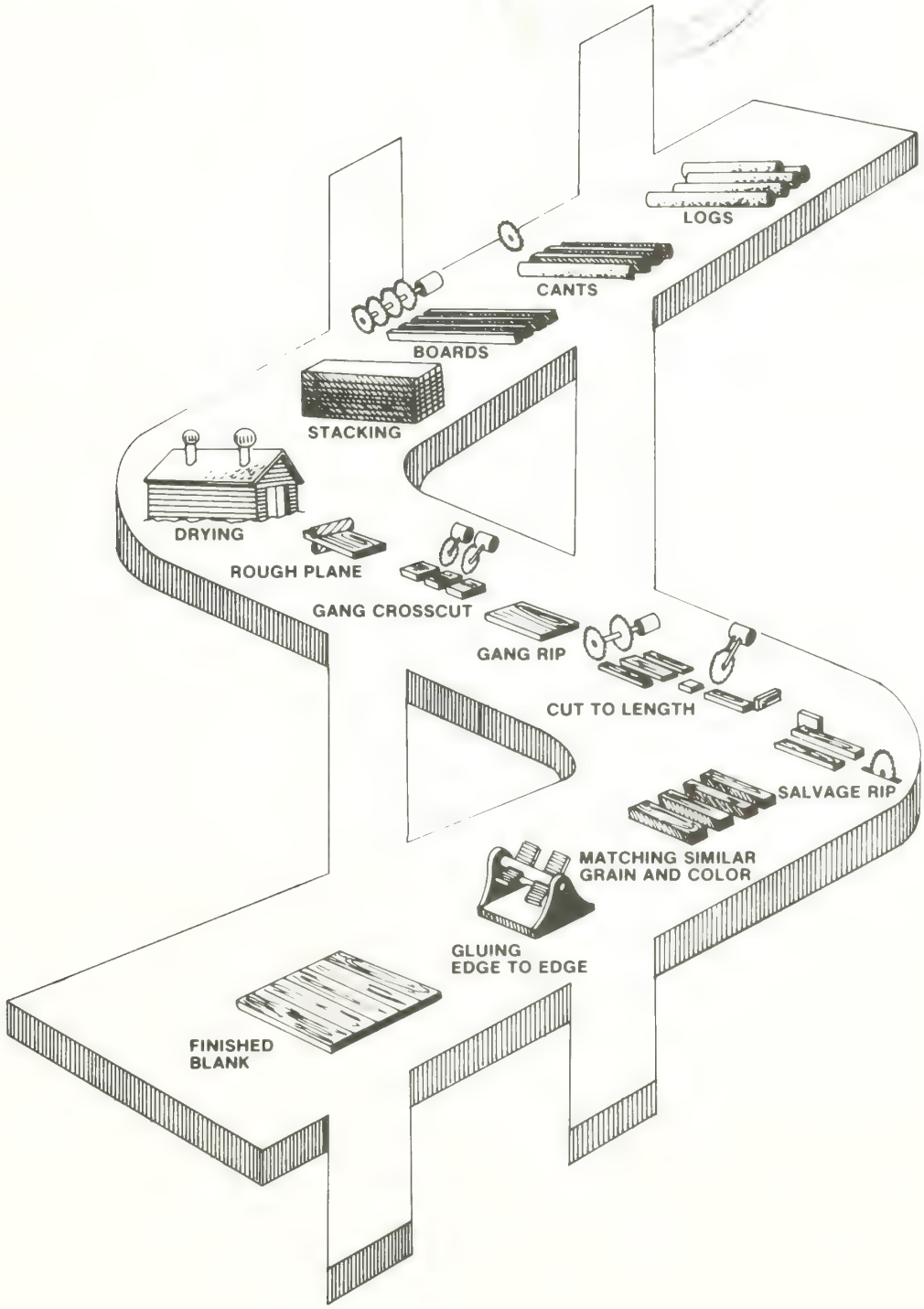
**Northeastern Forest
Experiment Station**

Research Paper
NE-551

1984

System 6 Alternatives: An Economic Analysis

Bruce G. Hansen
Hugh W. Reynolds



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Manuscript received for
publication 17 January 1984.

Abstract

Three System 6 mill-size alternatives were designed and evaluated to determine their overall economic potential for producing standard-size hardwood blanks. The study focused on developing standard discounted cash flow measures. Internal rates of return ranged from about 15 to 35 percent after taxes. Secondary effort was directed at providing accounting cost summaries to facilitate cost comparison of standard-size blanks with rough-dimension stock. Cost per square foot of blanks ranged from about $0.88 to $1.19, depending on mill size and the amount of new investment required.

Introduction

System 6 is a new technology that, when combined with the production of standard-size hardwood blanks, provides a way to convert a low-grade resource into high-value products. A standard blank is a piece of solid wood (generally constructed from edge-glued pieces) of specified length, width, thickness, and quality. Specifications for standard-size blanks have been developed from an analysis of rough-dimension part sizes required by 32 major manufacturers of furniture and kitchen cabinets. Sizes have been determined so that rough-dimension parts can be processed efficiently from blanks with a minimum amount of loss in kerf and end trim. Several manufacturers have found System 6 blanks satisfactory in the production of fine solid-wood products.

System 6 production technology has been developed through numerous trials conducted at the Northeastern Forest Experiment Station's Forestry Sciences Laboratory at Princeton, West Virginia. However, a thorough economic analysis of System 6 is needed to see if investment is justified. In this paper we examine three alternative plant sizes that represent a range in investment and output by those who may wish to convert existing dimension operations to the manufacture of blanks, or by those who wish to produce blanks for sale on the open market. Also, we discuss the many general issues in investment analysis that affect results.

Additional information on System 6 technology and standard-size blanks is found in Araman et al. (1982); Reynolds and Gatchell (1982); Reynolds and Araman (1983); Reynolds et al. (1983); and Reynolds and Hansen (1984).

Study Design

Mill Alternatives

The three options for producing blanks with System 6 technology are referred to as the standard-mill, the mini-mill, and the maxi-mill alternatives. While all three were profitable, there were obvious economies associated with increased scale of operation.

The standard-mill was assumed to have a daily input of 16 Mbf (thousand board feet) of 6-foot cants. This resulted in production of about 7,200 ft^2 of blanks. Production of the mini-mill was one-half that of the standard-mill, while production of the maxi-mill was double that of the standard-mill. In each case, we assumed that the mill operated 240 days per year, and that each Mbf of input resulted in 450 ft^2 of blanks.

The standard-mill design is shown in Figure 1. This mill consisted of a resaw mill, a rough mill, and a glue room. The design included a forced-air predryer with a capacity of 250 Mbf, three kilns with a total capacity of 60 Mbf, and a boiler. This mill had a capability of sustained production of 16 Mbf of green cants into 7.2 Mbf of C1F (clear-one-face) panels (blanks) with a single shift. The initial investment required for this plant was $1.7 million excluding working capital (Table 1).

The mini-mill was designed to be built adjacent to an existing dimension facility. Another goal was to limit the initial investment to about $1 million. This goal was partially achieved by eliminating the following equipment:

Item	*Number*
Defect saws	2
Sorting table	1
Salvage ripsaw	1
40-clamp carrier	1
Cutoff saw	1
Stacker	1
Strapping machine	1

Further reduction in the initial cost was obtained by eliminating separate kiln facilities and reducing boiler size. The prestickered packages of System 6 boards were dried with kiln facilities of the dimension mill at a marginal cost of $35 per Mbf. The mini-mill processed 8 Mbf of cants into 3,600 ft^2 of blanks daily. Maxi-mill production was achieved by running the standard-mill on two shifts per day. To support the doubling of production, additional drying capacity was necessary. This increased the initial investment by approximately $300,000 over that required for the standard-mill. The maxi-mill processed 32 Mbf of cants into 14,400 ft^2 of blanks daily.

Methods of Analysis

Discounted cash flow. Our analyses of the System 6 standard-mill, mini-mill, and maxi-mill centered on the theoretically preferred measures of discounted cash flow (DCF): the internal rate of return (IRR) and the net present value (NPV). These measures assess the relationship between initial investment requirements and anticipated future after-tax cash flows (Appendix A).

Another measure closely associated with the NPV is the profitability index (PI), also known as the benefit/cost ratio. This measure expresses the NPV in terms of the investment base from which it results and allows the NPV from different-size investments to be compared.

Accounting-based cost summaries. In addition to the DCF analyses, we developed accounting-based manufacturing cost summaries for those who might use System 6 to replace existing dimension production facilities. In the case of replacement, we cannot account for all circumstances in which DCF analyses are used. For example, in developing data for such analyses, it is customary to

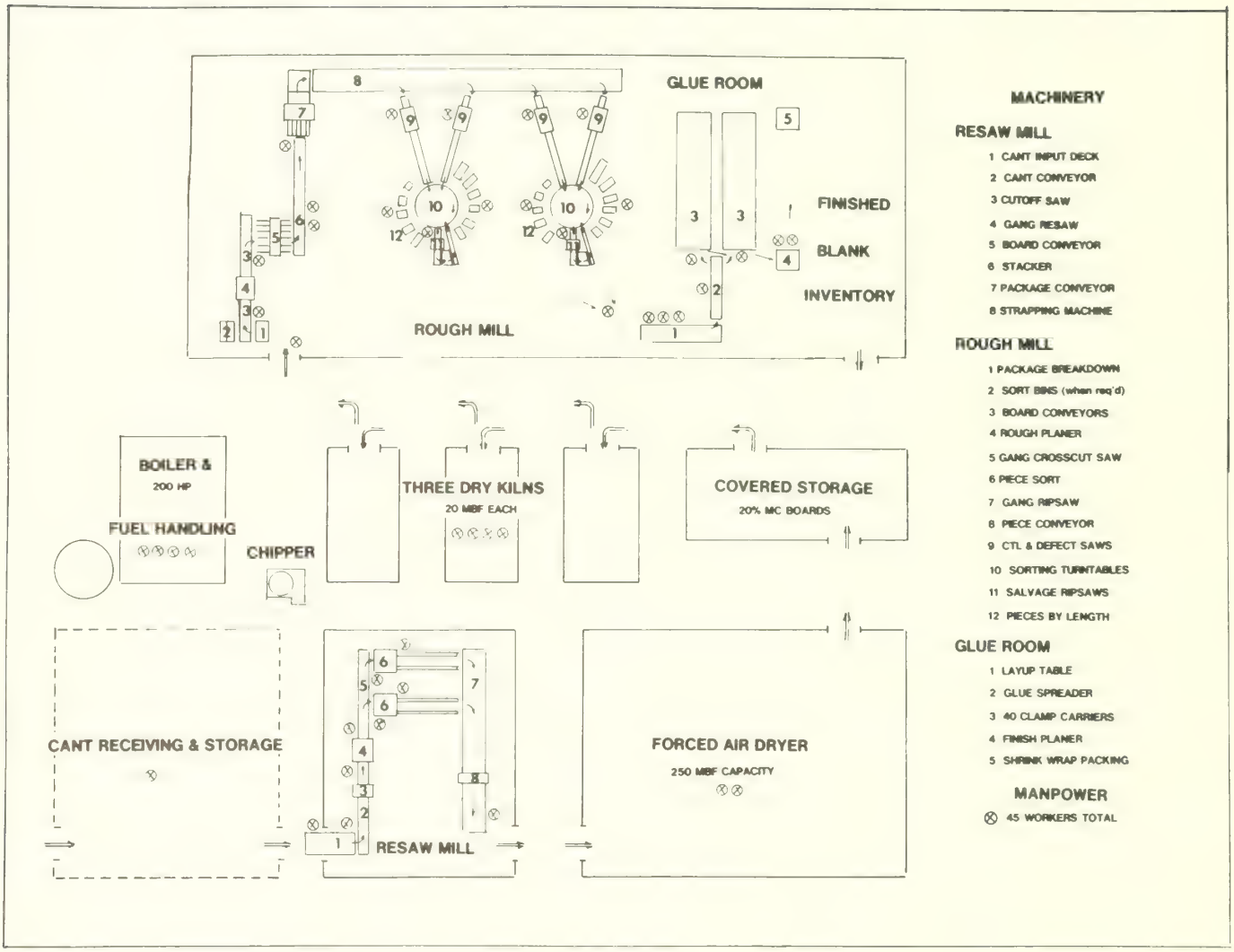

Figure 1.—The standard System 6 mill (input capacity: 16 Mbf per shift).

Table 1.—System 6 equipment costs for a standard-mill (prices current: October 1982)

Item	Cost
	Dollars
Primary processing machinery	
Cant gang resaw: 11 saw (100 hp)	22,000
Cant cutoff saw: 6 × 25 (15 hp)	9,000
Receiving deck, unscrambler and conveyors (25 hp total)	36,000
2 manual board stackers at $7,500 each (10 hp total)	15,000
Board conveyors and strapping machine (25 hp total)	30,000
Hog/screen chip-pac and infloor sawdust/refuse conveyor (75 hp total)	48,500
Forklift, 4,000 pounds propane	12,500
	173,000
Secondary processing machinery	
Package breakdown hoist and 3-way sort conveyors (25 hp total)	24,000
Rough planer: 2-side, 4 × 12 spiral knives (50 hp total)	30,000
Gang crosscut saw: 5-saw, variable spacing (30 hp total)	54,000
Modified gang ripsaw (100 hp)	60,000
Piece conveyors and piece sort station (25 hp total)	24,000
4 defecting saws at $8,500 each (20 hp total)	34,000
2 rotary sorting tables at $4,500 each (10 hp total)	9,000
2 salvage ripsaws with return conveyors at $8,500 each (50 hp total)	17,000
Forklift, 4,000 pounds propane	12,500
Glue spreader and conveyors and panel layup tables (15 hp total)	15,000
Clamp carriers: 80 section at $65,000; 40 section at $35,000 (air motors)	100,000
Panel trimsaw: 3-saw variable spacing (30 hp total)	35,000
Blank planer: 2-side, 2 × 30 spiral knives (75 hp total)	40,000
Dust collection system and bins (50 hp total)	65,500
Minicomputer with 250K memory	10,000
	530,000
Dryers, kilns, and boilers	
Boiler, 200 hp and fuel handling/storage	300,000
250 Mbf dryer at $0.60/board foot capacity	150,000
3–20 Mbf kilns at $2.70/board foot capacity	162,000
2-forklifts, 4,000 pounds propane at $12,500 each	25,000
	637,000
Land	
Improved 8 acres at $12,500/acre	100,000
Buildings	
Primary plant 40 × 70 feet = 2,800 ft² at $24/ft²	67,000
Secondary plant 40 × 150 feet = 6,000 ft² at $24/ft²	144,000
Boiler 40 × 40 feet = 1,600 ft² at $12.50/ft²	20,000
Air-dry lumber storage 40 × 60 feet = 2,400 ft² at $12/ft²	29,000
	260,000
Total investment	
Primary plant machinery	173,000
Secondary plant machinery	530,000
Subtotal	703,000
Dryers, kilns, and boilers	637,000
Buildings	260,000
Subtotal	897,000
Land	100,000
Total	$1,700,000

assume that complete new facilities are to be constructed. This allows us to have access to relevant price information. By contrast, those who replace existing facilities will most likely convert some portion of their existing plant and equipment to the System 6 venture. Still other components of the existing facility may no longer be necessary; their sale can be used to further offset initial investment requirements. Therefore, the number of investment requirement possibilities can be as large as the number of possible investors.

Similarly, it is difficult to derive possible revenues when replacement is involved. If products are to be sold on the market, we generally can use the current market price of the same or substitute products to estimate revenues. But when conversion leads to "revenues" because of internal cost savings, we cannot account for the many likely possibilities among investors.

The manufacturing cost summaries follow general accounting practice and provide manufacturing costs on a square foot of output basis. Where costs are comparable to those of the process being studied for replacement, further individual DCF-based investigation of the actual costs and revenues involved should be undertaken. Help in undertaking a study of this nature generally is available from university forestry extension personnel and personnel in the various schools of business, the Small Business Administration, and private business consultants. The computer program by Harpole (1978) used in our analyses has been adapted to run on all major computer systems.

Investment Parameters

Initial Costs

Working capital is an important component of the initial cost of each alternative. Working capital refers to that required to purchase and maintain raw material, work-in-process, and finished goods inventories, and also to support credit sales to the extent that they were made. We assumed a 30-day inventory of raw material and a combined amount for finished-goods inventory and credit sales equal to 30 days' output. These requirements were proportional to the level of production.

Variable Operating Costs

The cost of raw material was estimated at $180 per Mbf. This figure was based on a cost of approximately $45 per cord for low-quality hardwood bolts (or about $100 per Mbf). To this we added a cost of $50 for sawmilling into cants and $30 for transportation to the System 6 mill. Each Mbf of cants yielded 450 ft² of blanks. The cost of the raw material was independent of the volume purchased.

We found that the cost of System 6 raw material is unaffected by species, as species generally is not a consideration in the market for low-grade roundwood. Thus, the price for this material is related directly to the cost of manufacture. As a result, whether purchasing oak, cherry, or another species, the estimated price for cants of $180 per Mbf that we used in our analyses should hold firm.

Labor costs for millworkers were assumed to average $6 per hour. This is broken down into a wage of $4.60 per hour plus mandatory fringes of 30 percent of $1.40 per hour. We believe this figure is adequate since most jobs within the System 6 mill require only minimum skills and training. We included a 2-week vacation allowance. Another 2 weeks of lost time was assumed during which workers were not compensated. Supervisory employees average $10 per hour in wages and fringe benefits.

The standard-mill, including kilns, employed 47 people—45 production and 2 supervisory. Mini-mill employment consisted of 23 production workers and 2 supervisory personnel. The maxi-mill labor force was twice that of the standard-mill in both production workers and supervisory personnel.

Raw material and labor accounted for nearly 85 percent of the total variable cost of the standard- and maxi-System 6 alternatives. Remaining costs were accounted for by utilities, supplies, and selling expenses. Mini-mill raw material and labor costs accounted for about 80 percent of the total variable cost. The remaining 20 percent was utility, supply, selling, and dry-kiln contract costs. Table 2 includes a detailed breakdown of the variable operating costs for each alternative.

Fixed Operating Costs

Fixed costs for each alternative were composed of management and administrative costs, insurance costs, and maintenance expenses (Table 2). In terms of the management and administrative staff, the standard-mill had an assumed staff of two administrators and one secretary; the mini-mill had a staff of one administrator and one secretary; the maxi-mill had two administrators and two secretaries.

For all alternatives, insurance and maintenance costs were based on a percentage of the total cost of plant and equipment. Insurance was estimated at 2½ percent annually. Maintenance was estimated at 10 percent annually and was based on initial machinery cost. This allowance would include expenditures for both parts and labor.

Revenues

Revenue estimates were obtained from the assumed sale of blanks on the open market at a price of $1.60 per square foot (Table 3). This price was equal to about 90 percent of the price received for rough dimension of similar quality. While mill residues were used to fire boilers, about twice as much was produced as was used. Although we did not include their sale in our analyses, it is possible that some investors will find a market for this surplus material.

Other Factors Affecting Investment

Besides the obvious factors that affect investment performance—initial amount of investment, operating costs, and revenues—others are not so obvious. These include the time period or useful life of investment; inflation; depreciation; sources and costs of funds; tax rates and tax credits; and the time required to reach full production. Appendix B includes a detailed discussion of these issues and of our treatment of these factors with respect to the System 6 investment opportunity.

Comparative Cash Flow Summaries

The derivation of net after-tax cash flows in most years is straightforward. We subtracted operating costs and depreciation from revenues, computed taxes, and then added depreciation to the after-tax income. However, there are some instances where other considerations affect the net after-tax cash flows. First, additional working capital is required to cover inventories as the plants move to full production. Second, the maxi-mill requires additional capital investment in year 2 to cover increased kiln and boiler capacities. Third, Harpole's (1978) cash flow program allows for the complete writeoff of depreciation in the year it occurs whether or not there is sufficient income from the project itself. In such instances, it is implicitly assumed that there is additional income for the investor, allowing the complete and immediate writeoff to occur. This treatment enhances the net after-tax cash flow only to the extent of the tax benefit derived from depreciation. Finally, proceeds from the assumed sale of land and from real assets in an amount equal to their undepreciated value, plus the return of working capital, are added to the operating cash flows at the end of year 10. Once after-tax net cash flows have been determined, the DCF measures are calculated. Cash flow summaries for the three mill alternatives are included in Tables 4-6. The accounting-based summaries do not require cash flow summaries since they focus on the costs occurring in just 1 year at full production.

Table 2.—Variable and fixed operating costs for the System 6 mill alternatives

Cost item	Year 1	Year 2	Years 3 to 10
	Dollars		
	MINI-MILL		
Variable costs			
Raw material	172,800	345,600	345,600
Labor	237,000	316,000	316,000
Supplies	15,000	20,000	20,000
Utilities	20,000	26,000	26,000
Selling expense	34,560	69,120	69,120
Drying	50,250	67,000	67,000
Fixed costs			
Management and admin.	50,000	50,000	50,000
Insurance	25,000	25,000	25,000
Maintenance	68,000	68,000	68,000
Total	672,610	986,720	986,720
	STANDARD-MILL		
Variable costs			
Raw material	345,600	691,200	691,200
Labor	435,000	580,000	580,000
Supplies	31,250	41,500	41,500
Utilities	41,750	55,500	55,500
Selling expense	69,120	138,240	138,240
Fixed costs			
Management and admin.	80,000	80,000	80,000
Insurance	40,000	40,000	40,000
Maintenance	134,000	134,000	134,000
Total	1,176,720	1,760,440	1,760,440
	MAXI-MILL		
Variable costs			
Raw material	345,600	691,200	1,382,400
Labor	435,000	580,000	1,160,000
Supplies	31,250	41,500	83,000
Utilities	41,750	55,500	111,000
Selling expense	69,120	138,240	276,480
Fixed costs			
Management and admin.	80,000	80,000	95,000
Insurance	40,000	40,000	48,000
Maintenance	134,000	134,000	165,000
Total	1,176,720	1,760,440	3,320,880

Table 3.—Revenues for the System 6 mill alternatives

Mill type	Year 1	Year 2	Years 3 to 10
	Dollars		
Mini	691,200	1,382,400	1,382,400
Standard	1,382,400	2,764,800	2,764,800
Maxi	1,382,400	2,764,800	5,529,600

Table 4.—Standard-mill cash flow summary

Year	Facilities and working capital investment	Revenues	Operating costs	Depreciation	Net after-tax cash flow
	Thousands of dollars				
0	1,857				−1,857
1	156	1,382	1,177	168	32
2		2,765	1,760	253	659
3		2,765	1,760	237	652
4		2,765	1,760	219	643
5		2,765	1,760	210	639
6		2,765	1,760	63	571
7		2,765	1,760	54	567
8		2,765	1,760	54	567
9		2,765	1,760	54	567
10		2,765	1,760	45	1,218

Table 5.—Maxi-mill cash flow summary

Year	Facilities and working capital investment	Revenues	Operating costs	Depreciation	Net after-tax cash flow
	Thousands of dollars				
0	1,857				−1,857
1	468	1,382	1,177	168	− 280
2	313	2,765	1,760	253	346
3		5,530	3,321	259	1,312
4		5,530	3,321	254	1,309
5		5,530	3,321	242	1,304
6		5,530	3,321	88	1,233
7		5,530	3,321	76	1,228
8		5,530	3,321	76	1,228
9		5,530	3,321	73	1,226
10		5,530	3,321	64	2,309

Table 6.—Mini-mill cash flow summary

Year	Facilities and working capital investment	Revenues	Operating costs	Depreciation	Net after-tax cash flow
	Thousands of dollars				
0	1,175				−1,175
1	79	691	673	124	− 11
2		1,382	987	185	299
3		1,382	987	175	294
4		1,382	987	168	291
5		1,382	987	165	290
6		1,382	987	22	224
7		1,382	987	19	222
8		1,382	987	19	222
9		1,382	987	19	222
10		1,382	987	16	563

Results of Analyses

Discounted Cash Flow Performance

The results of the DCF analyses of System 6 investment alternatives indicate that they are economically justifiable. As seen in Table 7, the IRR ranged from about 15 percent for the mini-mill to 35 percent for the maxi-mill. This pattern was similar for NPV's and PI's; both increased with the scale of operation. With respect to the alternatives we have presented, there seemed to be a direct relationship between size and performance. And as was readily apparent, the returns to the maxi-mill were considerably better than those to the other two. However, we believe that increasing mill size and operation much beyond the parameters established for the maxi-mill would pressure the upper limits of the mill's technological and physical capabilities. Consequently, additional improvement in performance is unlikely.

While all three alternatives seemed economically justified under the conditions prescribed, we examined performance under changes in some of the key inputs: initial investment, sales, price, and fixed and variable operating costs. Keep in mind that we were not concerned so much with increases in sales and prices as we were with declines. Conversely, decreases in investment and operating costs were not of the same concern as were increases. Figures 2-4 were derived using Harpole's (1978) CFA program and depict what happened to the internal rate of return (IRR) when either a 10- or 20-percent increase or decrease was imposed on the selected input while all others remained unchanged. As can be seen, mini-mill IRR was sensitive to any increase in cost or decrease in either the level of sales or price of blanks. A 10-percent change in any one of these resulted in an IRR below 15 percent.

By contrast, the standard-mill offered some security against the adverse effects of changes in the selected revenue and cost items. For this alternative, only a 20-percent reduction in the volume of sales or in the price of blanks will cause the IRR to fall below 15 percent.

Table 7.—Economic performance criteria for the three System 6 design alternatives

Mill type	IRR	NPV	PI
	Percent	*Thousands of dollars*	
Standard	24.5	892	1.48
Mini	15.0	0	1.00
Maxi	35.0	2,763	2.47

The maxi-mill was the most certain to earn at least a 15-percent return. In fact, in no instance did the return fall below 15 percent. The lowest IRR (19 percent) resulted from a 20-percent drop in the unit price.

We did not measure compound effects. Certainly, in those instances where both volume and price were to fall or where several cost items were to increase in conjunction with a decline in revenues, all alternatives would be in jeopardy.

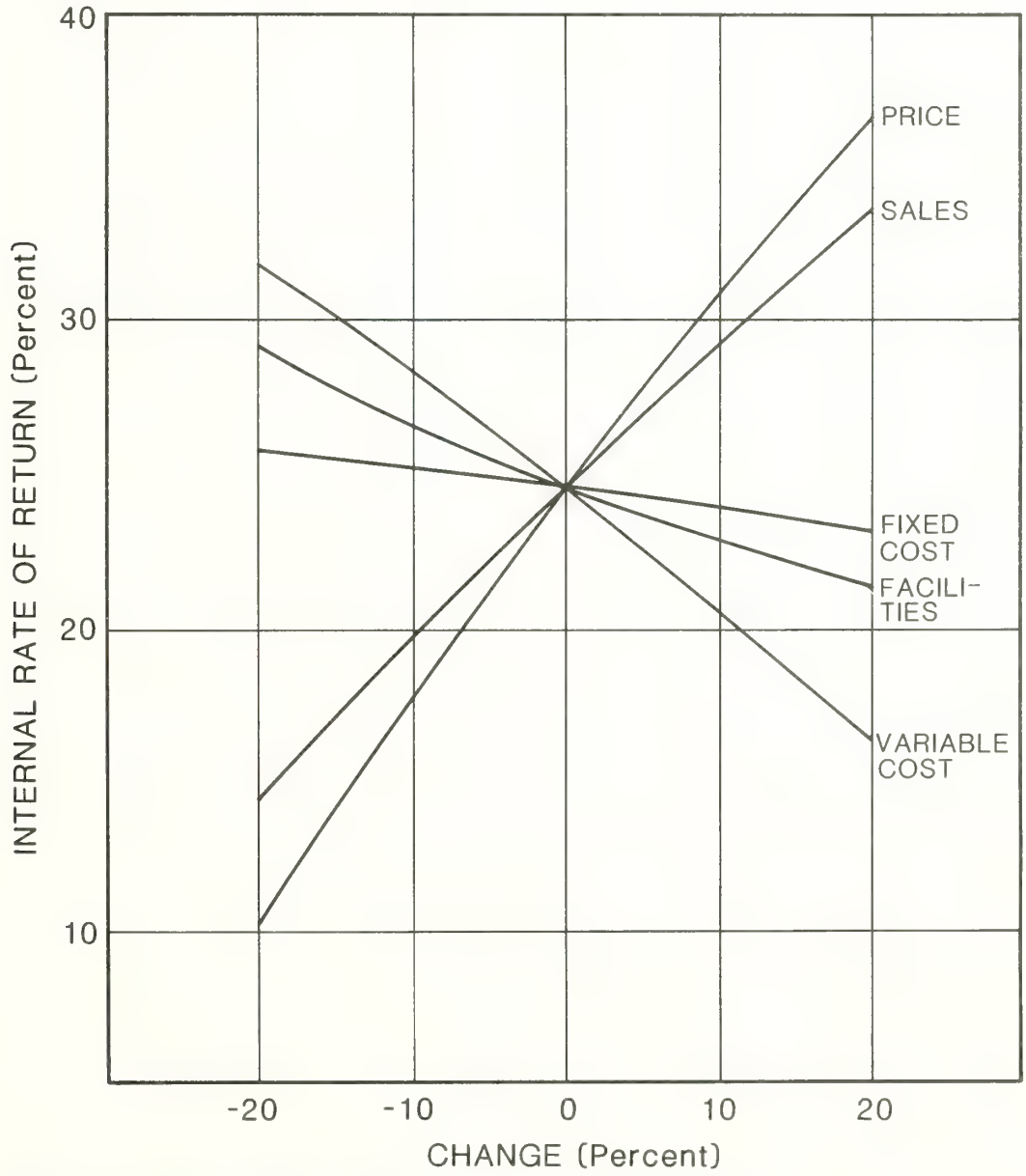

Figure 2.—Sensitivity of IRR to changes in selected inputs: standard-mill.

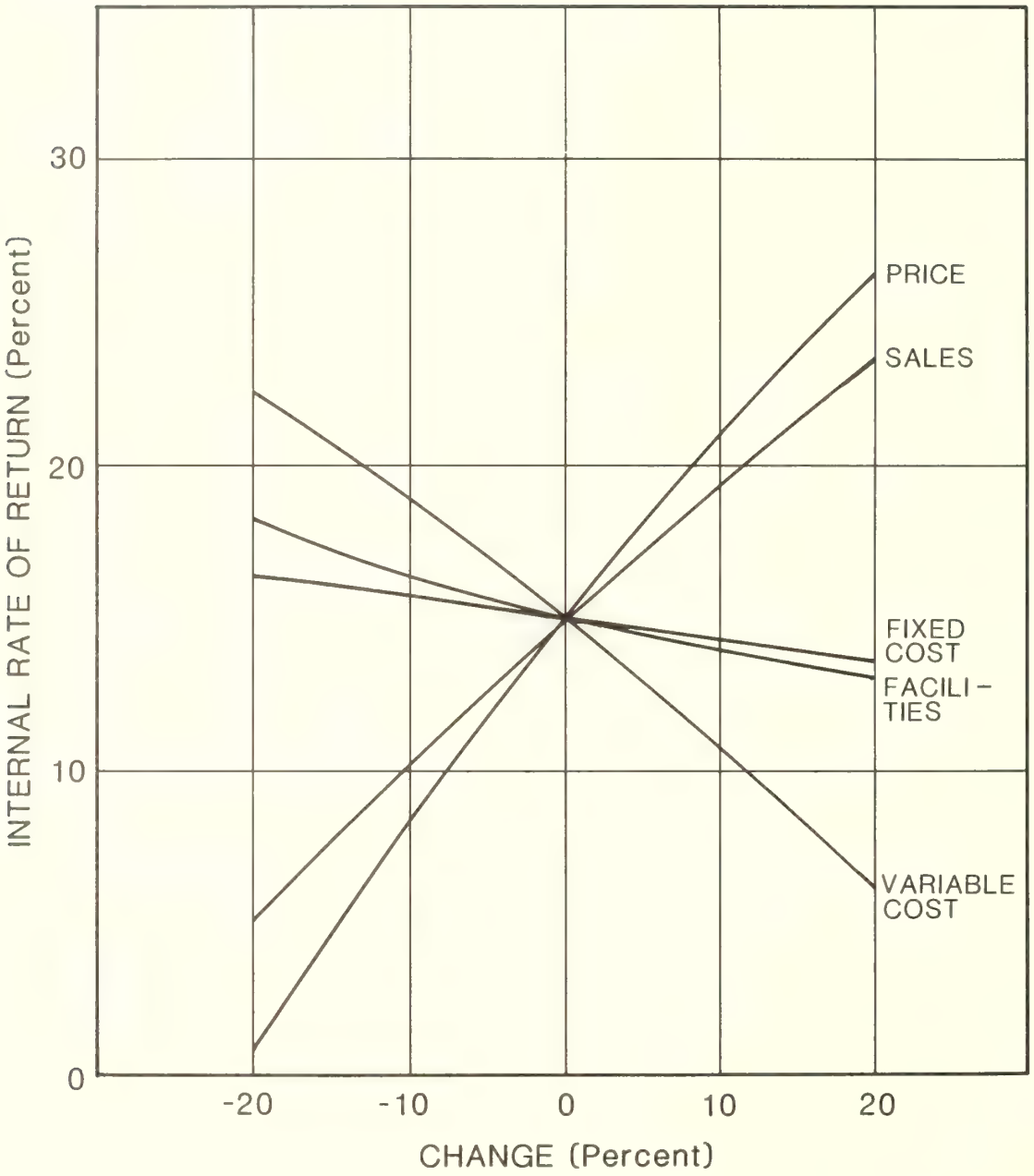

Figure 3.—Sensitivity of IRR to changes in selected inputs: mini-mill.

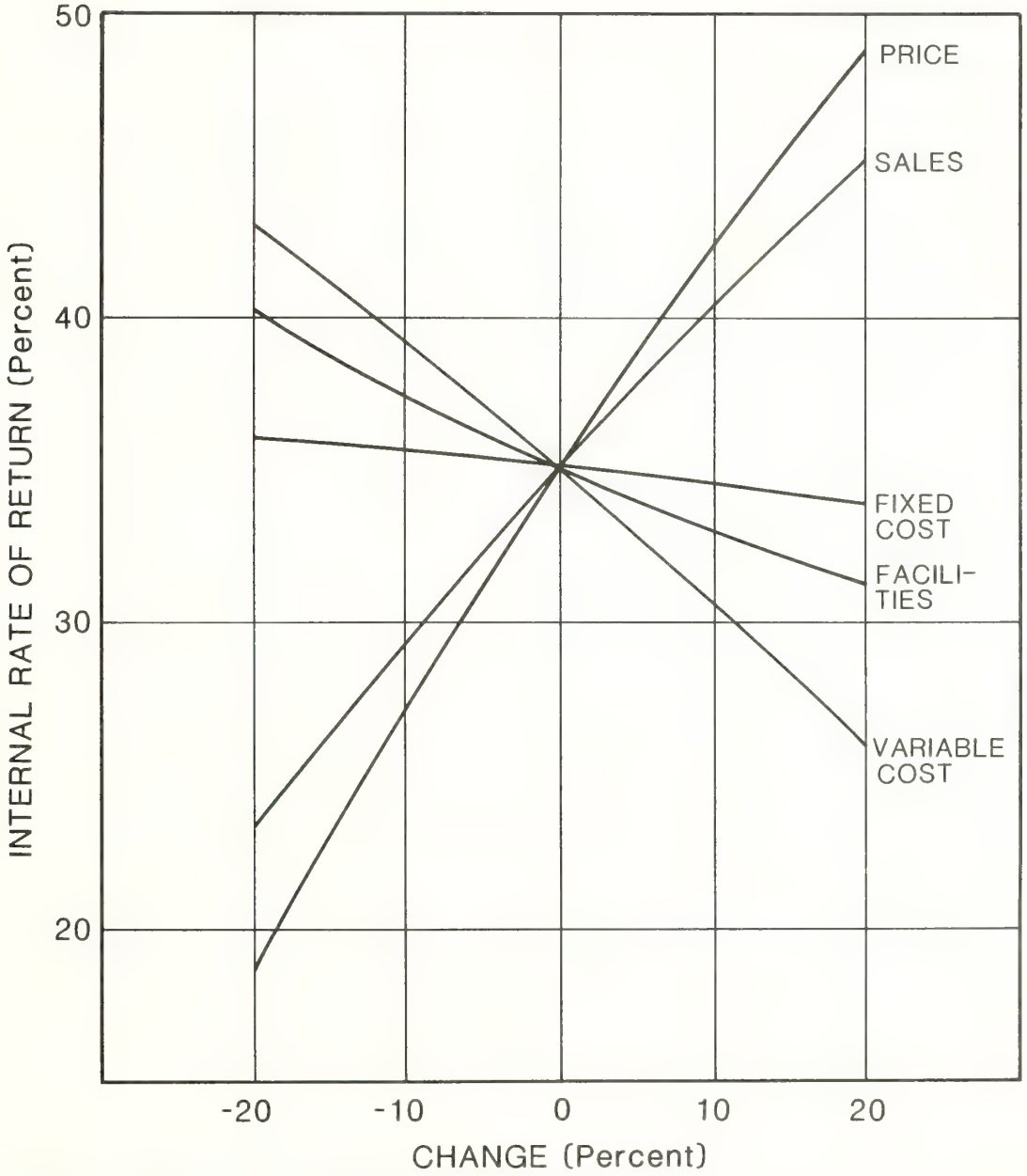

Figure 4.—Sensitivity of IRR to changes in selected inputs: maxi-mill.

Accounting-Based Cost Estimates

The accounting cost summaries are provided for those investors who may look at blanks as a replacement for conventional dimension production. As stated earlier, we are unable to perform DCF analyses to cover all possible differences in the level of investment and potential "revenues" that might exist among individual investors.

The cost data in Table 8 for the three alternative ventures were developed to be generally comparable to manufacturing costs information provided by the accounting profession. In these summaries, manufacturing costs were broken into three components—variable costs, fixed costs, and depreciation expense which was used to account for the building and equipment "used up" in the production process. If these costs are near those of an existing dimension manufacturer, a more thorough, individually tailored, DCF investigation of the System 6 opportunity might be warranted. This investigation would focus on the relationship between the added (marginal cost) investment required and the potential cost savings (marginal benefits) to be realized over the life of the investment.

In looking at the accounting cost summary, note that depreciation was calculated for each of five levels of investment, which ranged from zero to 100 percent of those estimated for a complete new plant and equipment. This was done for two reasons. First, it provides a means for more accurate comparison of the inflated depreciation costs of a plant placed in service today with the uninflated depreciation costs of one placed in service some time ago. Rough comparison can be facilitated by multiplying the total investment cost of a complete new facility by the ratio between the producer price index during the past investment and that of the present. Once determined, the row in Table 8 representing an investment nearest this amount (i.e., 0, 25, 50, 75, 100 percent) will be more accurate for cost comparison. Second, the different levels of investment can be used to evaluate prospective costs more accurately where a portion of existing plant and equipment are to be either used or sold; this reduces the amount of new investment required.

The costs per square foot of C1F standard-size blanks for the standard-mill ranged from about $0.94 assuming no capital investment was required to nearly $1.04 for a complete new facility. Mini-mill costs were considerably higher starting at about $1.06 per square foot and ending at $1.19. The maxi-mill had the greatest economies, with costs per square foot ranging from approximately $0.88 to $0.94. Whether or not these costs are attractive depends on the current costs of the individual dimension producer.

Table 8.—Cost per square foot of C1F standard-size blanks for each System 6 alternative given different levels of capital investment

Item	Standard	Mini	Maxi
	Dollars		
Variable cost	0.792	0.897	0.792
Fixed cost	.147	.166	.089
Total operating cost	.939	1.063	.881
Capital investment cost			
0 percent	.000	.000	.000
25 percent	.025	.032	.015
50 percent	.049	.064	.029
75 percent	.074	.095	.044
100 percent	.098	.127	.058
Total cost			
Low	.939	1.063	.881
High	1.037	1.190	.939

Conclusion

Each of the three alternative operations for producing standard-size blanks from low-grade hardwood material seems commercially viable. Our treatment of the many elements (Appendix B) considered in an economic analysis tended to impose the more stringent assumptions on anticipated costs and revenues. However, we could not allow for all situations and recognize that for some individuals the situation will differ from that which we have described. Sensitivity analyses provide an indication as to the most critical areas. Those who are contemplating an investment in System 6 will need to trace our steps in determining more exactly the costs and revenues they will incur.

To duplicate results in actual production, management will need to ensure that the production rates and costs established in the analyses are maintained, and that the operation is kept in production for the prescribed time once the mill is operating. The latter requirement can be best ensured by developing and maintaining a viable market for System 6 standard-size panels.

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Appendix A

The mathematical formula of the IRR can be expressed as:

$$\sum_{i=1}^{N} \frac{NATCF_i}{(1 + IRR)^i} = I_o$$

In essence, the IRR is a rate of discount that when divided into the net after-tax cash flows (NATCF) of each period (i) during the life of the investment (N) reduces their sum to an amount equal to the initial investment (I_o). The IRR is found via an iterative process.

The IRR can be thought of as a rate of earnings similar to the simple interest earnings of a home mortgage loan. I_o is essentially the same as the original amount of a mortgage loan or principal and the $NATCF_i$ is comparable to the periodic payments. The IRR is comparable to the annual percentage rate of the mortgage loan. With any mortgage loan, the payment generally contains an amount to cover interest on the outstanding balance plus a return of principal. At the end of (N) payments, the loan is completely amortized. So, too, is the case with regard to earnings stemming from investment.

In most mortgage situations, payments are equal and of an amount sufficiently large to cover interest cost plus a portion of principal. However, this need not be the case for the same principles of simple interest to apply. For example, innovative financing arrangements have evolved that are designed to keep payments lower during the earlier years of a mortgage than what they ordinarily would be if equal. This is accomplished through what are termed "negative" payments to principal. Many investment situations may result in cash flows patterned in this manner.

The simple interest concept of the IRR differs from the concept where the IRR is presumed to represent a "compound" or "growth" rate of return. This latter concept assumes that any intermediate cash flows occurring during the life of the investment are reinvested at a rate equal to the IRR for the project. Such reinvestment opportunities may not always be available. Thus, to the extent that the actual rate of reinvestment differs from the IRR calculated for the project, the overall rate of "growth" under this concept will be affected.

The NPV formula looks quite similar to the IRR, however, there are some important differences.

$$\sum_{i=1}^{N} \frac{NATCF_i}{(1 + r)^i} - I_o = NPV$$

In this formula, the rate used to discount cash flows (r) is assigned. As a result, when the initial investment is subtracted from the discounted sum of the cash flows, the difference may be positive, negative, or zero depending in part on the rate of discount used. If the NPV is zero, r is equal to the IRR. Usually, r represents the minimum risk adjusted rate of return acceptable for investment. Consequently, projects with a negative NPV should be rejected. Final acceptance of projects with zero or positive NPV's (meaning returns equal to or above the minimum required) depends on the availability of funds and alternative opportunities.

The discount rate should reflect the after-tax, weighted average cost of capital. By using a weighted average, implicit recognition is given to the overall debt/equity structure.

In our studies of System 6 alternatives, we used a discount rate of 15 percent when deriving the NPV for each investment. This rate is consistent with that generally used by industry during the early 1980's (Gitman and Mercurio 1982). Obviously, no two investments need have the same capital structure or the same component costs. Therefore, we recognize that 15 percent may not be appropriate to all investors; however, it is important to note that the IRR sets an upper limit for the cost of capital below which any rate of discount used will result in a positive NPV estimate.

The final measure used in our analyses is the profitability index (PI). This measure also is known as the benefit/cost ratio and is derived as:

$$PI = \frac{NPV + I_o}{I_o}$$

This measure provides a look at the discounted returns (NPV) in terms of the investment on which it is based.

Appendix B

The following are less obvious factors involved in investment analyses that are not directly related to any particular investment, but that influence the results of such studies. In most instances, our approach in handling these factors resulted in a more conservative estimate of performance than had some other course been taken.

Time Period

In our analyses we have assumed a 10-year period over which to evaluate the investment. This period is fairly standard and can be supported rather easily.

First, and perhaps most important in supporting this choice, the discounted value of the dollar at current interest rates after 10 years makes up a relatively small percentage of the total revenue resulting from investment. For example, if we were to receive a dollar each year for the next 20 years and were to discount the value to the present using a discount rate of 10 percent, the dollars received after the tenth year would account for just 28 percent of the total. If a 20-percent rate of discount were used, the dollars received after the tenth year would be worth even less, only 14 percent of the total.

A second point that may be used to support the 10-year period relates to obsolescence. While it is possible that many plant facilities will last well beyond 10 years, they may become outmoded by advancing technology.

Third, the longer the period forecast for investment, the less reliable are the estimates made of the costs and revenues to be expected, and the greater is the degree of uncertainty that enters into the evaluation.

Finally, revenues lost by assuming the cessation of business activity in 10 years are partially offset by the assumed sale at the end of year 10 of land, real assets at their remaining undepreciated value, and the return of working capital resulting from the liquidation of inventories.

Inflation

Inflation has proven to be persistent, highly volatile, and unpredictable. Consequently, it is an extremely difficult issue to deal with. While it might be prudent to expect a continuation, we can only guess at the rate of inflation over the next 10 years. It is near impossible to accurately predict individual increases in the various cost and revenue items. An alternative sometimes used is to assume a uniform rate of increase in both costs and prices. Yet, this actually has the effect of accenting performance. And if the rate is overspecified, predicted performance may not be realized, the consequences of which may be extremely detrimental. Recognizing these difficulties, we have chosen to disregard inflation in costs and revenues and to assume constant costs and prices (i.e., constant net revenues) over the life of investment.

It is argued that if inflation is disregarded in determining future costs and revenues, the inflationary component of the cost of capital or discount rate should be similarly disregarded. We believe that to do this may be dangerous, especially if an investment is made today using a fixed inflated financial obligation and, subsequently, inflation is brought under control. Also, even what is referred to as the "real" rate of interest has itself become increasingly unstable in recent years. By using current capital cost estimates against the likelihood of constant costs and revenues, we better protect the investor against the negative risks of investment. And if a uniform rate of inflation does prevail, the consequence is that investment performance will exceed our estimates.

Depreciation

Depreciation, or capital recovery, is recognized in discounted cash flow analyses as it provides a shield from taxation for a portion of income equal to the amount of investment in buildings and equipment. DCF techniques recognize the time value of money; thus, the more accelerated the depreciation writeoff, the greater the benefits in tax-sheltered income. We use the recently legislated Accelerated Cost Recovery schedules for building and equipment capital cost recovery. Consequently, the full value (basis) of equipment is written off in 5 years. Building recovery during the first 10 years is based on full value and is allotted according to the 15-year schedule allowances for real assets placed in service during the sixth month of the tax year. The remaining value of these assets (27 percent of their cost) is recaptured through their assumed sale at the end of the tenth year.

Conversely, accounting theory recognizes depreciation as an expense and as a means to apportion that part of the building and equipment investment "used up" in the manufacturing process. Therefore, in constructing the accounting-based manufacturing cost summaries, we have chosen to apportion building and equipment costs equally over the 10-year period through depreciation calculated on a 10-year straight-line basis.

Sources of Funds

Confusion can sometimes arise as to the earnings potential of an investment vis-a-vis other alternatives available to an investor because of the inclusion or exclusion of debt and equity considerations in the investment analysis. Consequently, it is necessary that we clarify our approach. We do not directly consider the sources of capital that might make up the initial investment because of the likelihood that each investor will have a different set of financial arrangements, that is, different amounts of debt and equity and different component costs. Rather, our analyses focus on the returns to the *overall sum* of investment dollars.

This is not to say, however, that the results of individual financial arrangements cannot be discerned or used to evaluate the results of the System 6 analyses. To the contrary, by using the concept known as "weighted average cost of capital"

(WACC), individual investors can determine the overall return on investment (discount rate) that would be required to repay debt plus interest costs and equity plus a desired profit. Likewise, knowing the IRR of an investment and the proportion and cost of debt used, the return to equity (profit) can be approximated.

The WACC takes the following form:

$$WACC \cong P_d C_d (1 - t) + (1 - P_d) C_e$$

where P_d = the proportion of the total investment financed by debt capital
C_d = the interest cost of debt capital
t = the tax rate
$(1 - P_d)$ = the proportion of the total investment financed by equity capital
C_e = the desired return (profit) to be earned by equity capital.

To use the WACC in determining the returns to equity, the following is used:

$$C_e \cong \frac{IRR - P_d C_d (1 - t)}{1 - P_d}$$

Generally, if the IRR exceeds the after-tax cost of debt, then the return to equity will exceed the IRR. This is due to the leverage effect gained by employing debt capital. Conversely, if the IRR should lie below the after-tax cost of debt, the returns to equity will be less than the overall returns (IRR) to the project.

Theoretically, returns to equity can be quite large in cases where the IRR exceeds the after-tax cost of debt and where debt is a significant proportion of the overall investment. In reality, overall indebtedness usually is kept at reasonable levels and rarely exceeds 50 percent of the total capitalization of a particular firm.

In calculating the NPV, we used a discount rate based on an annual WACC of 15 percent. The WACC was based on a hypothetical financial arrangement calling for equal parts of debt and equity financing. The before-tax cost of debt was set at 18.5 percent and the desired rate of earnings on equity at 20 percent.

Taxes and Investment Tax Credits

For taxable income, we apply the Federal corporate maximum rate of 46 percent. However, we do not include state and local taxes. Even so, we believe this approach generally will overstate the tax burden of most corporate investors.

We chose to exclude the investment tax credit from our evaluations because it has a history of change, and because it is dependent on the past and current earnings of individual investors. By not including the investment tax credit, we have understated the return likely to be realized by most investors.

Phase In to Full Production

We believe it is realistic to assume that full production will not be reached in the first year of operation. Mechanical difficulties, problems stemming from labor and supervisory inexperience, and a host of other factors undoubtedly will arise. To account for these eventualities, we have constructed DCF analyses to allow for a gradual move to full production. For each alternative, full one-shift production is not reached until the second year. First-year revenues are determined at one-half the full one-shift level, and cost generally at three-fourths the full one-shift level. Maxi-mill full two-shift production is not reached until year 3. If you, the potential investor, can accelerate the move to full production, so much the better. But if full production is not achieved in the period used in our studies, performance will fall short of our estimate.

Hansen, Bruce G.; Reynolds, Hugh W. **System 6 alternatives: an economic analysis.** Res. Pap. NE-551. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1984. 14 p.

Three System 6 mill-size alternatives were designed and evaluated to determine their overall economic potential for producing standard-size hardwood blanks. Internal rates of return ranged from about 15 to 35 percent after taxes. Cost per square foot of blanks ranged from about $0.88 to $1.19, depending on mill size and the amount of new investment required.

ODC 836.1:651.7

Keywords: Low-grade hardwood utilization; blanks; dimension stock; investment analysis; discounted cash flow; internal rate of return

U.S. GOVERNMENT PRINTING OFFICE: 1984—705-029/532

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Research Paper
NE-557

1985

Cost and Production Analysis of the Bitterroot Miniyarder on an Appalachian Hardwood Site

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Manuscript received for
publication 6 August 1984

Abstract

An 18-horsepower skyline yarder was studied on a steep slope clearcut, yarding small hardwood trees uphill for fuelwood. Yarding cycle characteristics sampled include: total cycle time including delays, 5.20 minutes; yarding distance, 208 feet (350 feet maximum); turn volume, 11.6 cubic feet (24 cubic feet maximum); pieces per turn, 2.3. Cost analysis shows yarding costs will range from $18.00 to $36.00 per cunit, depending upon crew efficiency and yarding conditions.

Introduction

The harvest and utilization of small trees are essential to the intensive management of Appalachian hardwood forests. Thinnings on the better sites and harvest cuts on poorer sites require the removal of many trees 5 to 10 inches diameter breast height (d.b.h.). Much of the fuelwood now harvested from standing timber or salvaged from logging residue is also obtained from small-diameter trees or logs. Cable logging is often the preferred harvesting method for the steep slopes common to Appalachia because of reduced environmental damage. However, logging small trees with cable yarders is generally too costly considering the low value of the products removed. The high initial investment and extensive setup and rigging times associated with most cable yarders limit their application to high-volume or high-value removals (Matics 1982).

The Bitterroot Miniyarder was developed by the USDA Forest Service, Missoula Equipment Development Center, for cable yarding small trees and logging slash on steep slopes. This small and very mobile cable yarder is relatively inexpensive to own and operate, quick to setup, and easy to operate (USDA Forest Service 1983). These characteristics identify the Bitterroot Miniyarder as a machine with the potential for reducing the cost of cable yarding small hardwood trees on steep slopes.

This small skyline yarder was tested in the South and the West (American Pulpwood Association 1983, Brown and Bergvall 1983, Cubbage and Gorse 1984). To obtain detailed cost and production information for eastern hardwood applications, the small yarder was studied logging a steep slope Appalachian site. The objectives of this study were to determine production rates and costs for the Bitterroot Miniyarder and to identify those factors that affect yarding cost.

Yarding Operations

The Bitterroot Miniyarder was studied yarding fuelwood from a 2-acre clearcut block on the Jefferson National Forest in Virginia. On this unit, 200 trees per acre larger than 4 inches d.b.h. were harvested, yielding 1,350 cubic feet per acre of wood and bark. The cutting unit was located in a poletimber stand that contained a few scattered low-quality sawtimber trees. The d.b.h. of cut trees averaged 7.7 inches, and the diameter distribution shows that more than 90 percent of the trees harvested were 10 inches d.b.h. or smaller (Fig. 1). Total height of the dominant and codominant trees ranged from 50 to 60 feet. The species composition was predominantly chestnut oak and scarlet oak with minor components of hickory, red maple, and pitch pine.

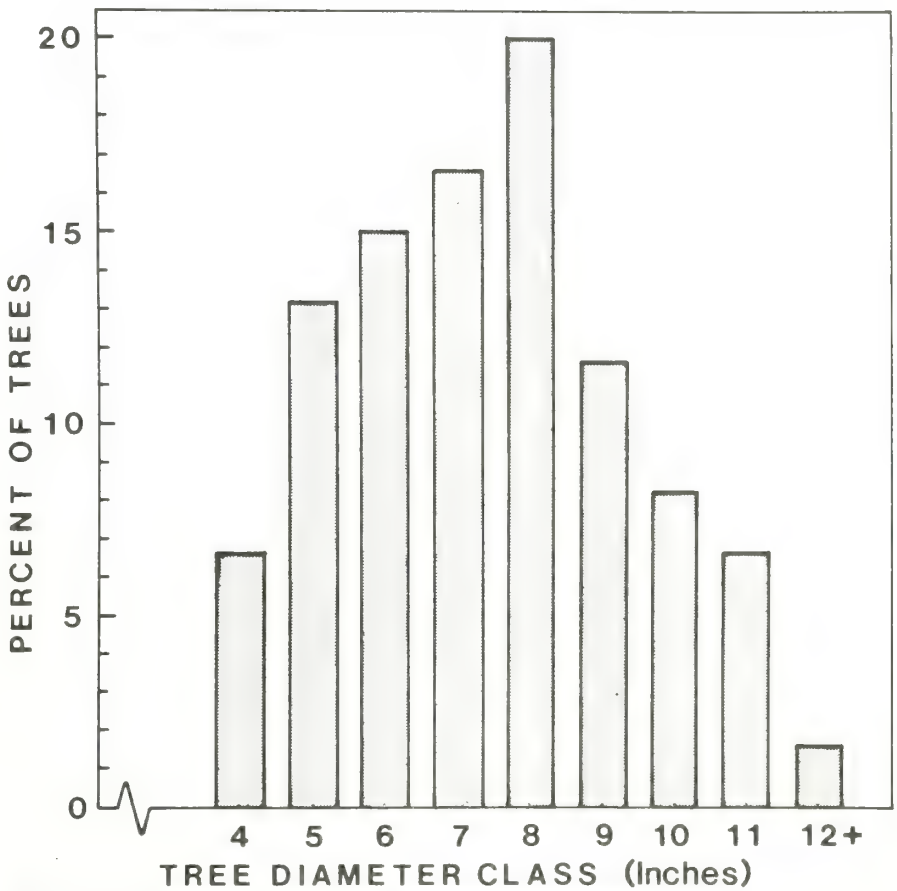

Figure 1.—The diameter distribution of merchantable trees on the logging site.

All trees larger than 1.0 inch d.b.h. were felled before yarding, but few trees smaller than 4.0 inches d.b.h. were actually yarded. Trees 4.0 inches d.b.h. and larger were limbed and topped to a variable top diameter as small as 2.0 inches diameter outside bark. Sawtimber-size trees were bucked into log lengths. The resulting piece-volume distribution shows that the volume of most pieces yarded was less than 10 cubic feet (Fig. 2). Piece volume averaged 5 cubic feet.

The small yarder was mounted on a two-wheeled trailer that could be towed by a pickup truck (Fig. 3). With the exception of the original ¼-inch diameter skyline that had been replaced with approximately 640 feet of ⅜-inch cable, the following specifications provided by Missoula Equipment Development Center describe the yarder tested.

Weight: 1,600 pounds rigged

Engine: 18-hp Briggs and Stratton,[1] twin cylinder, air cooled, electric start

Transmission: Sundstrand series 15 hydrostat

Axle: Dana Spicer GT-20 with 72-tooth spur gear

Skyline and Mainline Drums: 800 feet of ¼-inch cable, 0 to 2,000 pound line pull, 0 to 400 ft/min line speed

Mainline Clutch: Dog type

Brakes: Band type, mechanically operated, 12¾ inch diameter

Boom: 2¾-inch pipe A-frame, 17½ feet long, 180 degrees fairlead swivel, manually raised and lowered

Controls: 15-foot mechanical push/pull cable

During each yarding cycle, the live skyline was lowered for unhooking the chokers at the landing. The skyline was also periodically lowered to permit the chokersetters to move the carriage stop, which was clamped on the skyline. The small Christy carriage was locked on the skyline at the carriage stop, releasing the mainline to be pulled laterally by the chokersetters. As many as five wire-rope chokers were used when yarding very small pieces. When a turn of choked pieces was laterally yarded to the carriage, a ball attached to the mainline released the skyline lock and simultaneously locked the carriage to the mainline for the trip to the landing. The lift provided by the skyline generally kept the leading end of the pieces off the ground and free from stumps and slash.

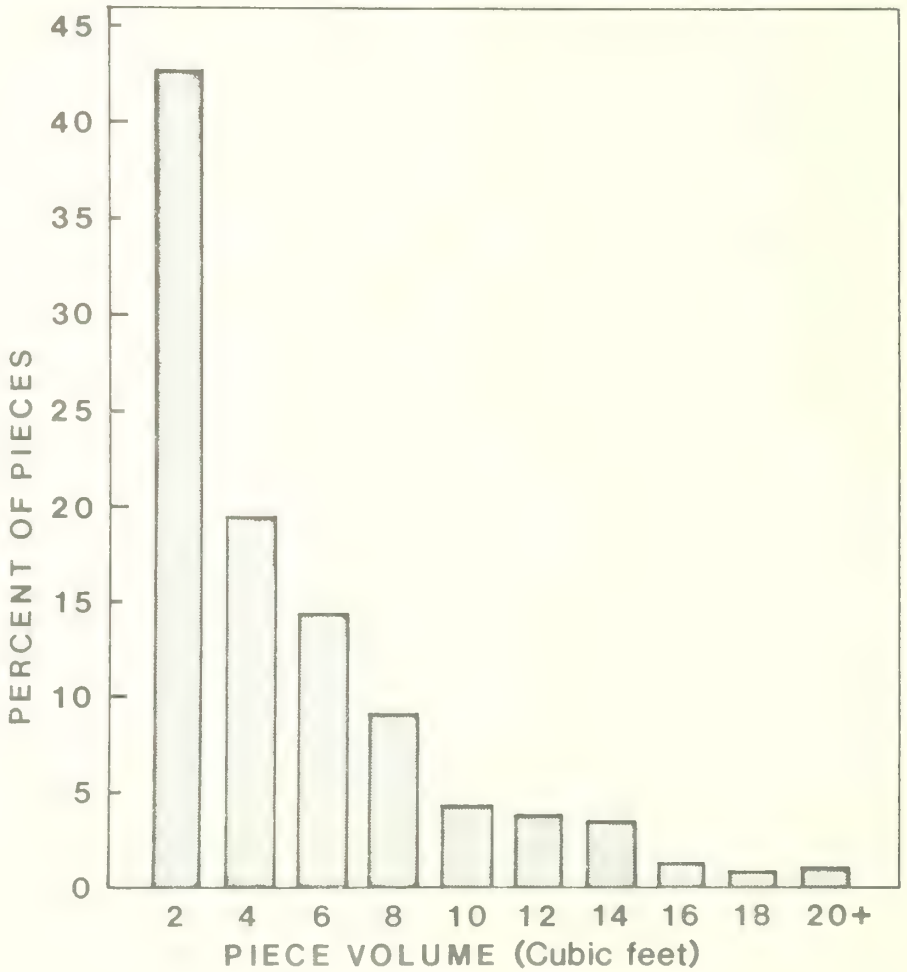

Figure 2.—The distribution of piece volume in cubic feet by percent of pieces yarded.

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Figure 3.—The Bitterroot Miniyarder mounted on a two-wheeled trailer.

The fan-shaped clearcut block was yarded uphill to a single landing located below the yarder (Fig. 4). The slope distance from the yarder to each of the four tailholds used to anchor the skyline ranged from 390 to 490 feet. Tailholds were rigged at a height of 2 to 3 feet by attaching the skyline to large standing trees located outside of the unit boundary. The slope of the skyline corridors ranged from 15 to 40 percent.

The Forest Service logging crew consisted of a yarder operator, two chokersetters, and one chaser unhooking at the landing. A tractor operator also used a small crawler to clear the landing and deck the yarded wood along the access road for sale at roadside as fuelwood. The tractor and operator were not included in the time study or the cost analysis.

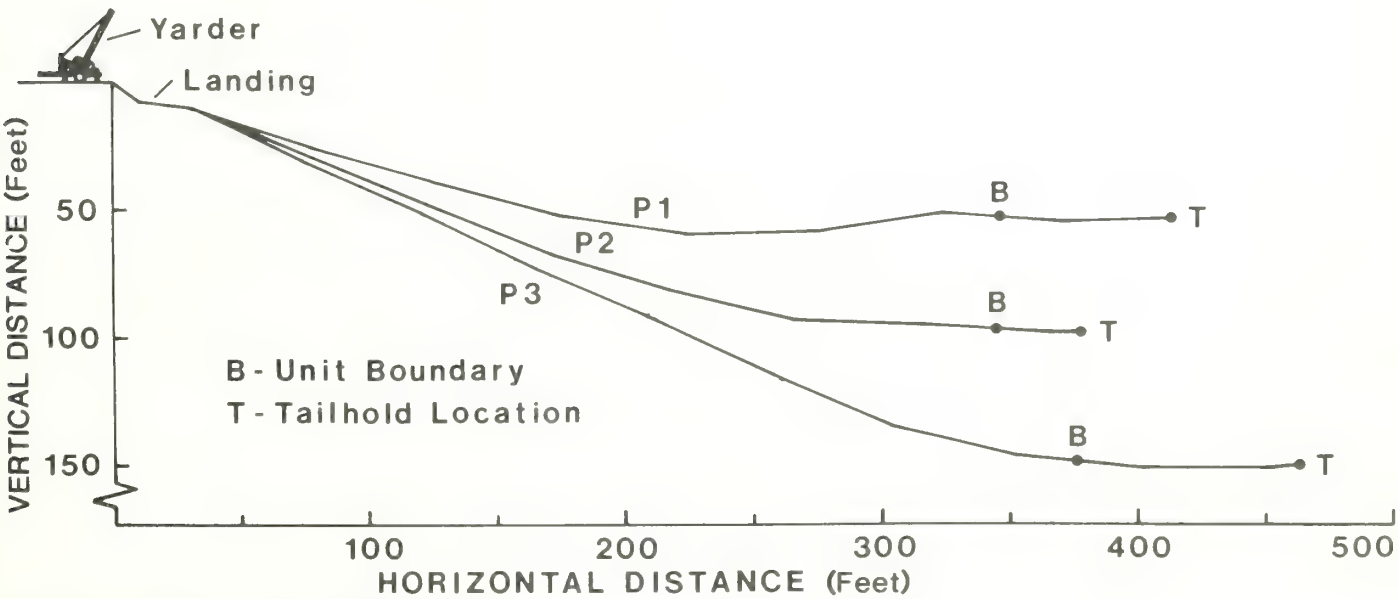

Figure 4.—Ground profile of three skyline roads.

Study Methods

A time study of the yarding operation was conducted using continuous timing over the span of each yarding cycle. Start and stop times were recorded for the productive and delay portion of each of the five major yarding cycle elements:

- Outhaul starts when the carriage leaves the landing and ends when the carriage hits the skyline stop releasing the mainline.
- Hooking starts when the mainline is released and ends when the chokers are hooked and the yarder operator is signaled to begin lateral yarding.
- Lateral yarding starts with the signal to begin lateral yarding and ends when the turn is laterally yarded, releasing the carriage lock.
- Inhaul starts when the carriage lock releases and ends when the turn reaches the landing.
- Unhooking starts when the turn reaches the landing and ends when pieces are unhooked, the skyline is raised, and the carriage begins to leave the landing.

In addition to yarding time data, yarder cycle characteristics were recorded, including: slope yarding distance, the distance from the landing to the carriage stop measured along the slope; slack-pulling distance, the distance from the skyline stop to the farthest piece hooked; number of pieces hooked; and the dimensions of each piece including both end diameters outside bark and length. From piece dimensions, piece volumes and total turn volumes were estimated. Piece and turn weights were estimated from the volumes using conversion factors developed by Timson (1975). For the species mix sampled, the conversion factor used was 59 pounds per cubic foot of wood and bark.

Linear regression methods were used to determine the functional relationships between site factors and yarding cycle time, and yarding element times. The objectives of this analysis were to identify those factors that affect yarder productivity and to develop equations for predicting cycle time so that yarding conditions could be used to predict yarder production.

The static mainline pull at a 250-foot-slope yarding distance was measured using a dynamometer anchored to a stump. For the three skyline road profiles shown in figure 4, the payload capability of the system was estimated using the handheld calculator programs developed by Falk (1981). These programs include the effects of partial load suspension, which was appropriate for this application since logs were dragged rather than yarded fully suspended.

The yarding cost model developed by Peters (1984) was used to estimate yarding cost and to predict the response of yarding cost to changes in operating efficiency and changes in piece size and volume per acre. This model uses the inputs listed below to estimate the time required to yard a given unit, the production rate, and the cost per unit of production.

Site specific variables

- Volume harvested per acre
- Average piece volume
- Harvest unit area
- Percent slope
- Geometric parameters required to compute average slope yarding distance and lateral yarding distance

Yarder specific variables

- Hourly cost of yarder and crew
- Cycle time regression coefficients
- Yarder payload capacity
- Load curve statistics to estimate average volume per turn and number of pieces per turn from average piece volume

Operation specific variables

- Time to move and set up yarder
- Time change to a new skyline corridor
- Downtime for mechanical or system delay
- Operational delay time during yarding cycle

Time Study Results

The yarding operation was observed a total of 22.4 scheduled work hours. Two changes of skyline corridor required a total of 2.1 hours. Of the remaining 20.3 hours, the yarder operated 19.7 hours. Detailed cycle time and production data were collected from 16.1 hours of yarder operating time that included 13.2 hours of delay-free yarding time. Within this time span, 186 turns were yarded producing 427 pieces and 2,162 cubic feet of wood and bark. The estimated weight of the pieces yarded was 64 green tons. The average productivity of the yarder was 134 cubic feet or 4 tons per productive hour, and 164 cubic feet or 4.8 tons per delay-free hour.

The following summary of cycle characteristics defines the yarding conditions sampled:

	Average	*Minimum*	*Maximum*
Slope yarding distance—feet	208	25	350
Slack-pulling distance—feet	26	1	80
Volume per turn—cubic feet	11.6	3	24
Weight per turn—pounds	680	180	1,400
Number of pieces per turn	2.3	1	5

The dimensions of the clearcut unit and the spacing of the skyline roads limited slope yarding distance to 350 feet and slack-pulling distance to 80 feet. With respect to payload, the yarder was thoroughly tested as several of the turns yarded represented the maximum capacity of this yarder. Because of the small diameter of the pieces yarded, the average volume yarded was only half of the maximum volume and as many as five pieces were yarded per turn. Volume yarded per turn seldom exceeded 16 cubic feet (Fig. 5).

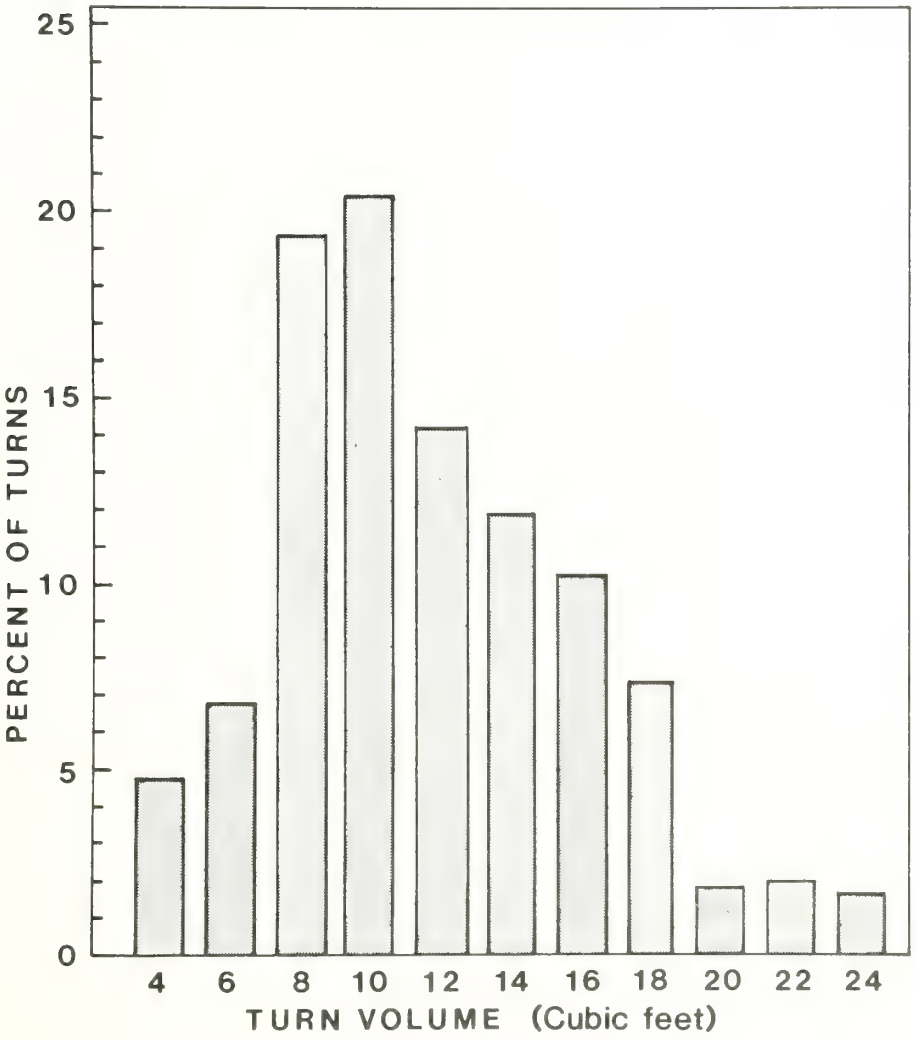

Figure 5.—The distribution of turn volume in cubic feet by percent of turns yarded.

Delay-free cycle time averaged 4.25 minutes per turn, including 0.48 minutes outhaul time, 1.46 minutes hooking time, 0.33 minutes lateral yarding time, 0.89 minutes inhaul time, and 1.09 minutes unhooking time (Table 1). Together, hooking and unhooking accounted for 60 percent of delay-free yarding time. The time required to move the turn of logs from the stump to the landing includes lateral yarding and inhaul, and accounts for less than 30 percent of delay-free cycle time.

Yarding delays averaged 0.95 minutes per turn, increasing the average total cycle time to 5.2 minutes. Half of all turns samples encountered delays that averaged 1.9 minutes. Delays in outhaul, hooking, and inhaul showed low frequencies of occurrence that ranged from 0.02 to 0.08 per turn. The average duration of these delays ranged from 1.0 to 2.9 minutes per delay (Table 2). Because of the low frequencies, the average delay time per turn was only 0.05 minutes for outhaul, 0.08 minutes for hooking, and 0.12 minutes for inhaul (Table 2). Collectively, these delays accounted for 26 percent of all yarding delay.

Collectively, lateral yarding delays and unhooking delays accounted for 74 percent of all yarding delay time. Both types of delay occurred with a frequency of 0.20 delays per turn. Average delay time per cycle was 0.38 minutes for lateral yarding and 0.32 minutes for unhooking (Table 2). Nearly all lateral yarding delays occurred when excessive loads were hooked or heavy logging slash covered the pieces and the turn had to be rehooked or bucked before the small yarder could move the turn to the carriage. Half of the unhooking delay time was incurred when the incoming turn hung on previously yarded pieces that extended over the downhill edge of the small landing. Other unhooking delays occurred while the tractor cleared the landing or when the carriage stop was moved.

Table 1.—Statistical summary of delay-free yarding element time.

Yarding element	Mean	Standard deviation	Minimum	Maximum
	Minutes			
Outhaul	0.48	0.17	0.09	0.79
Hooking	1.46	.54	.38	3.14
Lateral yarding	.33	.31	.04	2.36
Inhaul	.89	.42	.18	3.38
Unhooking	1.09	.40	.39	2.80
Complete cycle	4.25	.96	1.65	7.65

Table 2.—The frequency and average duration of yarding delays, average delay time per cycle, and percent of delay time by yarding element.

Yarding element	Frequency	Average duration	Average[a] delay time	Proportion of delay time
	Delays/cycle	*Minutes/delay*	*Minutes/cycle*	*Percent*
Outhaul	0.02	2.33	0.05	5.3
Hooking	.08	1.03	.08	8.4
Lateral Yarding	.20	1.86	.38	40.0
Inhaul	.04	2.87	.12	12.6
Unhooking	.20	1.54	.32	33.7
Complete Cycle	.54	1.72	.95	100.0

[a]Not equal to product of frequency and duration due to rounding.

Mainline Test and Payload Analysis

The maximum static mainline pull at a 250-foot-slope yarding distance was 1,150 pounds by measurement. The measured mainline pull corresponds to a drum radius of 6.4 inches; the bare-drum radius is 3.4 inches. The pull at bare drum is calculated as the product of the measured line pull and the ratio of drum radii, or 1,150 (6.4/3.4) = 2,165 pounds, which agrees with published values of 2,000 pounds (American Pulpwood Association 1983). Measured line pull also correlates closely with the estimated weight of the maximum turn volumes yarded. The largest turn weighed an estimated 1,400 pounds, and only eight turns exceeded 1,100 pounds. When turn volumes approached 20 cubic feet, lateral yarding became increasingly difficult and delays more frequent. Delays related to the mainline pull were also encountered when heavy logging slash covered the pieces to be yarded. Comparison of mainline pull capacity to the Appalachian hardwood tree weights published by Wiant (1977) shows that only trees 10 to 11 inches d.b.h. or smaller can be yarded stem length to a 4-inch outside bark top diameter.

The estimated payload capability in the skyline corridor, limited by the mainline and skyline respectively, are: profile 1, 2,000 pounds and 2,360 pounds; profile 2, 1,780 pounds and 2,230 pounds; profile 3, 1,720 pounds and 1,770 pounds. Therefore, the skyline profile did not determine the payload capacity, but in all instances, the payload capacity was determined by the mainline pull required to breakout and laterally yard the turn to the carriage. If payloads were limited only by skyline payload capability, they could have been increased by 35 to 50 percent.

Regression Analysis Results

The independent variables tested in the regression analyses of delay-free cycle time and cycle element time include slope yarding distance, slack-pulling distance, number of pieces yarded per turn, and cubic volume per turn. Only variables that were significant at the 0.05 level are included in the final equation shown in table 3. With the exception of slack-pulling distance, all variables that appear in the element time equations also appear in the cycle time equation.

The results shown in table 3 indicate that the independent variables in the equations for outhaul time, inhaul time, and cycle time explained 32 to 84 percent of the variation sampled. The equations for hooking, lateral yarding, and unhooking time explained only 3 to 12 percent of the sampled variation. Increases in slope yarding distance, turn volume, and number of pieces hooked all result in increased cycle time.

Table 3.—Regression equations, where Y = delay-free yarding element time in minutes, X_1 = slope yarding distance in feet, X_2 = slackpulling distance in feet, X_3 = number of pieces per turn, and X_4 = volume per turn in cubic feet of wood and bark.

Yarding element	Equation	Regression	
		R^2	S.E.
Outhaul	$Y = 0.099 + 0.0018\ X_1$	0.84	0.07
Hooking	$Y = 1.182 + 0.1189\ X_3$	.06	.52
Lateral yarding	$Y = 0.228 + 0.004\ X_2$	.03	.30
Inhaul	$Y = -0.137 + 0.0035\ X_1 + 0.0254\ X_4$	.58	.27
Unhooking	$Y = 0.820 + 0.1189\ X_3$	.12	.38
Complete cycle	$Y = 2.148 + 0.0061\ X_1 + 0.1941\ X_3 + 0.0328\ X_4$	.32	.80

The relationships between predicted delay-free yarder production and slope yarding distance, turn volume, and number of pieces per turn are shown in figure 6. The equation P = (60/CT)V was used; where P is production, CT is delay-free cycle time, and V is turn volume. To simplify the illustration, the effects of pieces per turn are shown only for the 15-cubic-foot turn volume.

Because of the effect of yarding distance on cycle time, increasing yarding distance from 100 feet to 600 feet, reduces delay-free production from 163 to 89 cubic feet per hour when yarding a 10-cubic-foot turn (Fig. 6). Although cycle time also increases with turn volume, the effect of fewer turns per hour is offset by the additional volume. Yarding 300 feet, the increase in turn volume from 10 to 20 cubic feet boosts the production estimate from 122 cubic feet to 230 cubic feet per delay-free hour (Fig. 6).

The five production curves shown for the 15-cubic-foot turn volume in figure 6 indicate that production will decline when piece size dictates that more pieces must be hooked to maintain a specific turn volume. However, production will generally increase when hooking more pieces results in additional volume. Yarding 300 feet with a 2-piece, 15-cubic-foot turn, the estimated production rate is 185 cubic feet per hour. Adding a 5-cubic-foot piece and yarding a 3-piece, 20-cubic-foot turn, increases the estimated production rate to 230 cubic feet per delay-free hour (Fig. 6).

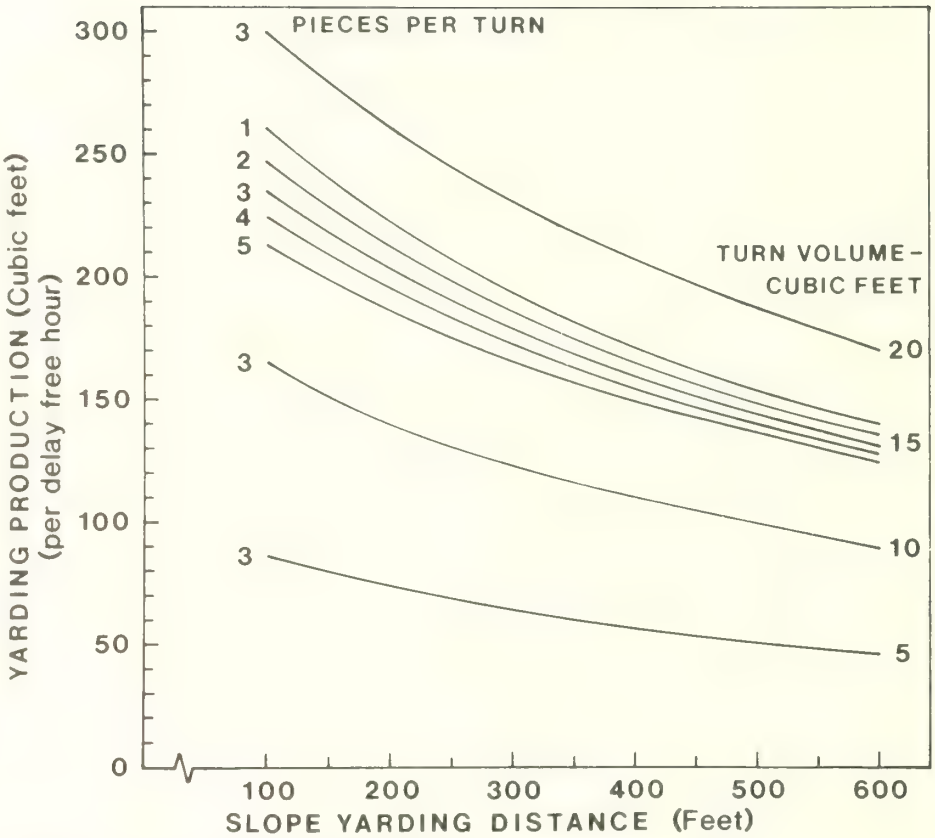

Figure 6.—The effects of slope yarding distance, pieces per turn, and volume per turn on estimated delay-free yarder production.

Yarding Cost Analysis

The total labor and equipment cost for the yarding operation; excluding felling, decking, and hauling, was estimated to be $270.00 per 8-hour day based upon 220 operating days per year. Fixed and operating costs for the yarder, chainsaws, and communications equipment totaled $62.00 per day (Appendix). Although the crew used handheld two-way radios for communications between the chokersetters and the yarder operator, the cost estimate includes the talkie-tooter type radio and transmitters normally used with cable yarders. Payroll cost for the crew of four with wages averaging $5.00 per hour and associated costs of 30 percent were $208.00 per day. Since labor cost represents 77 percent of the total cost, the daily yarding cost will be much more sensitive to changes in labor cost than to changes in the equipment costing assumptions.

The stump to landing yarding cost at the study site was estimated using the yarding cost model with two sets of inputs to show the effects of nonproductive time. Case 1 and Case 2 differ only with respect to the following nonproductive time elements. Case 1 represents the operation studied with the site, yarder, and operational variables required by the costing model being obtained from the study data. Because the short duration of the time study did not provide an adequate sample of downtime, the percent of scheduled operating time lost to mechanical or systems delays was assumed to be 10 percent in Case 1 and 5 percent in Case 2.

The increased efficiency shown in Case 2 might be expected as the crew became more experienced in cable logging and learned the limitations of the small yarder. The net result of these prospective improvements would be a 20 percent increase in production and a 17 percent reduction in yarding cost.

The yarding cost estimates in Cases 1 and 2 are specific to the conditions at the study site. These include an average piece volume of 5 cubic feet and a volume per acre of 1,350 cubic feet. To determine the sensitivity of yarding cost to changes in these two variables, the yarding cost model was applied to the conditions specified in Case 2, changing only volume per piece and volume per acre. Piece volume was incremented in 1-cubic-foot intervals from 3 to 12 cubic feet for each of three volume-per-acre levels—1,000, 2,000, and 3,000 cubic feet.

	Case 1	Case 2
Corridor change, minutes per move	60	30
Yarding delay, minutes per turn	0.95	0.50
Downtime, percent of scheduled operating time	10	5
Production rate, cunits per 8-hour day	7.6	9.1
Yarding cost, dollar per cunit	35.70	29.50

The results of this sensitivity analysis indicate that yarding costs will decline significantly with increases in either average piece size or volume per acre. Yarding 1,000 cubic feet per acre when piece size averages 4 cubic feet costs $34.00 per cunit. This compares to $18.00 per cunit when 3,000 cubic feet are yarded per acre and piece volume averages 12 cubic feet (Fig. 7).

These variations in yarding cost reflect a change in the expected production rate from 7.8 cunits to 15.0 cunits per 8-hour day. As volume per acre increases, proportionately more time is spent yarding and less time is spent moving the yarder or changing tailholds. Increasing average piece volume results in greater turn volumes and fewer pieces per turn.

Based upon the results of this study and the assumption incorporated into the cost analysis, $18.00 to $20.00 per cunit might well be the minimum expected yarding cost for the Bitterroot Miniyarder and a crew of four. The cost curves shown in figure 7 represent an efficient operation with an average yarding distance of 200 feet, and nonproductive time elements at the levels shown in Case 2. Furthermore, on sites with piece sizes consistent with the capacity of this yarder, volume per acre and average piece volume will seldom exceed those values that correspond with the cost curves at $20.00 per cunit. Under less favorable conditions, such as those at the study site, the costs would exceed $30.00 per cunit.

Aside from the increases in yarding production that are linked to crew efficiency and site conditions, yarding costs can also be controlled through crew size. The yarding operation studied used a crew of four. However, this and other small yarders can operate efficiently with crews of three or even two (Kellogg 1983, Brown and Bergvall 1983). At the wage rate used in the previous cost analyses, a crew of three cuts the daily cost of the yarding operation from $270.00 to $218.00 per day. This cost is $166.00 per day with a crew of two. To yard for $20.00 per cunit, the crew of four must produce 13.5 cunits per day, whereas the crew of three needs 10.9 cunits, and the crew of two only 8.3 cunits. Assuming that mechanical downtime, outhaul, lateral yarding, and inhaul are unaffected by crew size; there must be significant increases in the remaining time elements to offset the economic advantages of smaller crews.

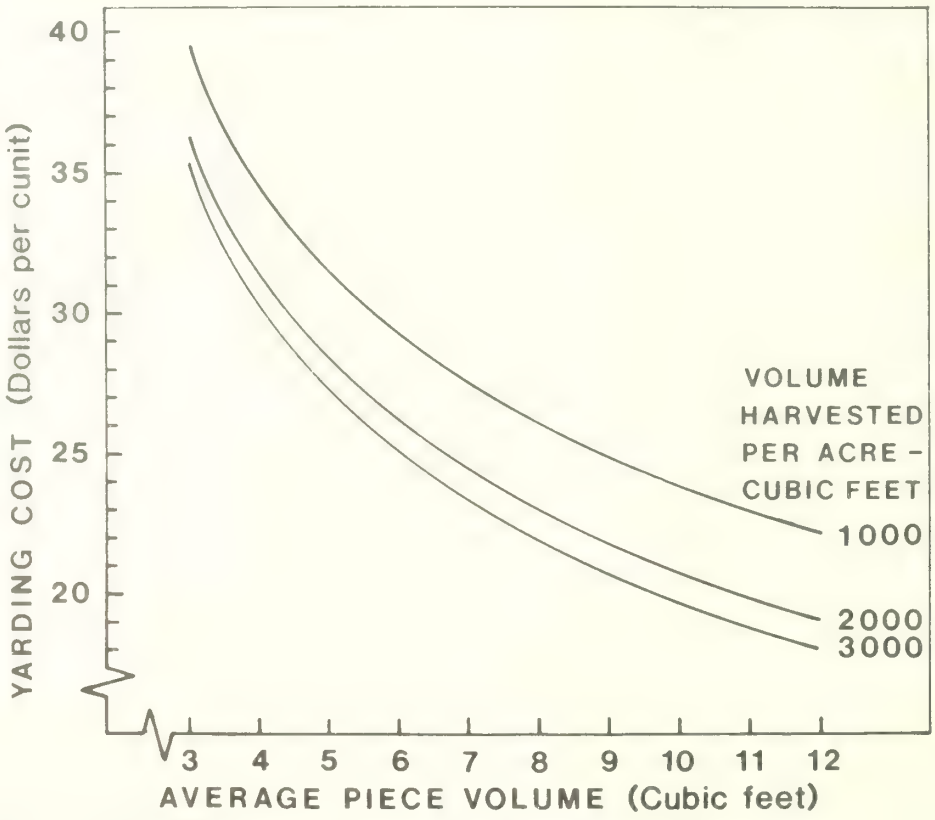

Figure 7.—The effects of volume harvested per acre and average piece volume on estimated yarding cost.

Conclusions

For successful application of cable yarding technology, the cost of yarding must be kept within the allowable limits. These limits will depend upon the forest management objectives of the landowner; the value attached to the environmental benefits of cable logging; and the difference between product value and the sum of additional costs such as felling, decking, loading, and hauling. With respect to yarding cost and potential applications, the two most important attributes of the Bitterroot Miniyarder are its low cost and low payload capacity.

To effectively manage the tradeoff between cost and capacity, it is essential to balance the cost of the yarding operation against the expected production rate. Although yarder production depends on crew efficiency and yarding conditions, it is constrained by yarder capacity. Due to the low cost of owning and operating this yarder, this balance would best be achieved through labor cost. Since the operation studied used a crew of four and the minimum crew size is two, the relationships between crew size, productivity, and yarding cost definitely warrant further investigation.

The material to be yarded must be compatible with the design capacity of the yarder. With the available line pull only poletimber and small sawtimber-size hardwood trees can be yarded in bole length or merchantable sawlog length pieces. Therefore, this yarder should be used to harvest small diameter sawlogs or sawbolts, pulpwood, or fuelwood. The material removed from thinnings will generally meet these criteria as will residue from regeneration cutting. Although the widespread need for thinning and the abundance of harvesting residue create numerous opportunities to use this yarder in the eastern hardwood region, its application will depend on local markets for these products.

Yarder capacity is an important consideration in planning the location of roads, landings, and corridors for all cable logging operations. Because of the capacity of this and other small yarders; felling, bucking, and other operational procedures must also be well planned. In the yarding corridors, even small trees should be felled and large tree tops lopped to avoid time consuming hangups. Directional felling will also reduce yarding delays, particularly in thinnings; and stems should be bucked to the capacity of the yarder. In thinnings, the chokersetter must position the carriage stop to keep turns within the lateral yarding corridor to reduce both delays and damage to the residual stand. The implementation of these essential practices will undoubtedly require an experienced and well-trained crew.

Landing and decking procedures must also be included in the planning process. When wood decked at the yarder interferes with yarding, either wood or the yarder must be moved. Often a tracked or wheeled skidder is used to swing the wood from the yarder to a loading deck. Although a small tractor could be used with this yarder, the cost of this machine will contribute significantly to the cost of the operation. When road and landing layout permits self-loading trucks to work directly from the yarder deck, the need for a swing tractor can be eliminated. Yarding closely spaced parallel corridors, the highly mobile yarder can also be moved frequently to build a series of decks along the access road.

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Appendix—Yarding Equipment Costs

FIXED-COST ESTIMATE

Equipment description	Life	Initial cost	Salvage value	Average annual investment	Annual fixed cost[a]
	Years			*Dollars*	
Cable yarder[b]	5	15,750	3,150	10,710	4,662
Chainsaws, 2	1	1,100	0	1,100	1,320
Radio and transmitters	4	4,500	0	2,812	1,688
Total annual fixed cost					7,670[c]

OPERATING-COST ESTIMATE

Equipment description	Operating cost items	Annual operating cost
		Dollars
Cable yarder	Maintenance and repair at 50% of depreciation	1,260
	Fuel at 4 gal/day, 220 days/year	1,100
	Filters, lube, and oil at 15% of fuel	165
	Cable, $1,250 with 2-year life	625
	Chokers, tools, and miscellaneous equipment	350
Chainsaws	Maintenance and repair at 100% depreciation	1,100
	Fuel and oil—220 days/year	725
	Miscellaneous equipment (bar, sawchain)	200
Radio	Maintenance and repair	350
Total annual operating cost		5,875[c]

[a]Depreciation plus sum of taxes, insurance, and interest estimated at 20 percent of average annual investment.
[b]Yarder without cable.
[c]Total annual fixed and operating cost = $13,545 and daily cost at 220 days/year = $61.56.

Baumgras, John E.; Peters, Penn A. **Cost and production analysis of the Bitterroot Miniyarder on an Appalachian hardwood site.** Res. Pap. NE-557. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1985. 13 p.

An 18-horsepower skyline yarder was studied on a steep slope clearcut, yarding small hardwood trees uphill for fuelwood. Yarding cycle characteristics sampled include: total cycle time including delays, 5.20 minutes; yarding distance, 208 feet (350 feet maximum); turn volume, 11.6 cubic feet (24 cubic feet maximum); pieces per turn, 2.3. Cost analysis shows yarding costs will range from $18.00 to $36.00 per cunit, depending upon crew efficiency and yarding conditions.

ODC 375.12:662.2

Keywords: Timber harvesting, cable yarding, logging, cost

☆ U.S. GOVERNMENT PRINTING OFFICE: 1985—505-028/545

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United States
Department of
Agriculture

Forest Service

**Northeastern Forest
Experiment Station**

Research Paper
NE-558

1985

The Determinants of Hardwood Lumber Price

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Abstract

Increased export activity in the hardwood and oak lumber markets coincided with rising prices of these commodities, which also coincided with an increase in the overall price level of all commodities. To determine the effect that exports have on the prices of hardwood and oak lumber, relative price models for these commodities were developed. Relative, rather than actual or nominal, price models were used to remove the effects of inflation. The models indicated that exports to Europe have had and will have an influence on hardwood lumber prices. Oak price seems to be more sensitive to changes in exports than overall hardwood lumber price. However, the main determinants of hardwood lumber and oak lumber prices were found to be domestic demand and millstock levels.

Introduction

Before 1973, exports of hardwood lumber were a minor part of the U.S. hardwood lumber market. Except for a temporary intrusion of Japanese buyers into the hard maple market in the early 1970's, there was little export activity in the hardwood lumber market until European buyers started to increase their purchases of oak lumber. In 1973, European demands accounted for only 5 percent of hardwood lumber exports; by 1980, exports to Europe accounted for 34 percent of the domestic hardwood lumber exported (Fig. 1). More significantly, the European share of oak exports increased from less than 6 percent in 1973 to more than 45 percent in 1980. These increases occurred during a period when total hardwood exports increased 91 percent and oak lumber exports increased 182 percent.

The export boom in the hardwood lumber market brought greater profits to producers and distributors of hardwood lumber, and to a small extent, improved the balance of payments with Western Europe. One suspected drawback of increased exports was increased lumber price, especially for oak.

The allegation that increased exports lead to increased hardwood lumber price results from the strong correlation between increased exports (Fig. 1) and increased nominal[1] lumber price (Fig. 2). The movement of hardwood lumber and No. 1 Common oak lumber prices seems to parallel exports to Europe, even though exports are primarily composed of grades Firsts and Seconds. Exports of higher grades indirectly affect overall prices of hardwood lumber because increasing the price of higher grade lumber increases the domestic demand pressures for lower grade lumber.

The trends exhibited in Figure 2 must be interpreted with some skepticism since inflation and expectations of further inflation were also prevalent during the period when exports increased. From 1973 to 1980, when oak price increased 116 percent, the general price index for all commodities rose by 100 percent. To assess the true effect of exports on the hardwood lumber market, the effects of inflation should be accounted for.

The prices of oak and hardwood lumber relative to the price of all commodities are shown in Figure 3. Although the relative price of oak has fluctuated above the 1967-100 baseline, these fluctuations are not nearly as dramatic as the increase in nominal oak price. The relative price of hardwood lumber has also tended to fluctuate above the baseline, but not to the same degree as oak lumber price. These fluctuations may indicate that exports did have some effect on domestic hardwood lumber prices; however, other factors such as demand and supply

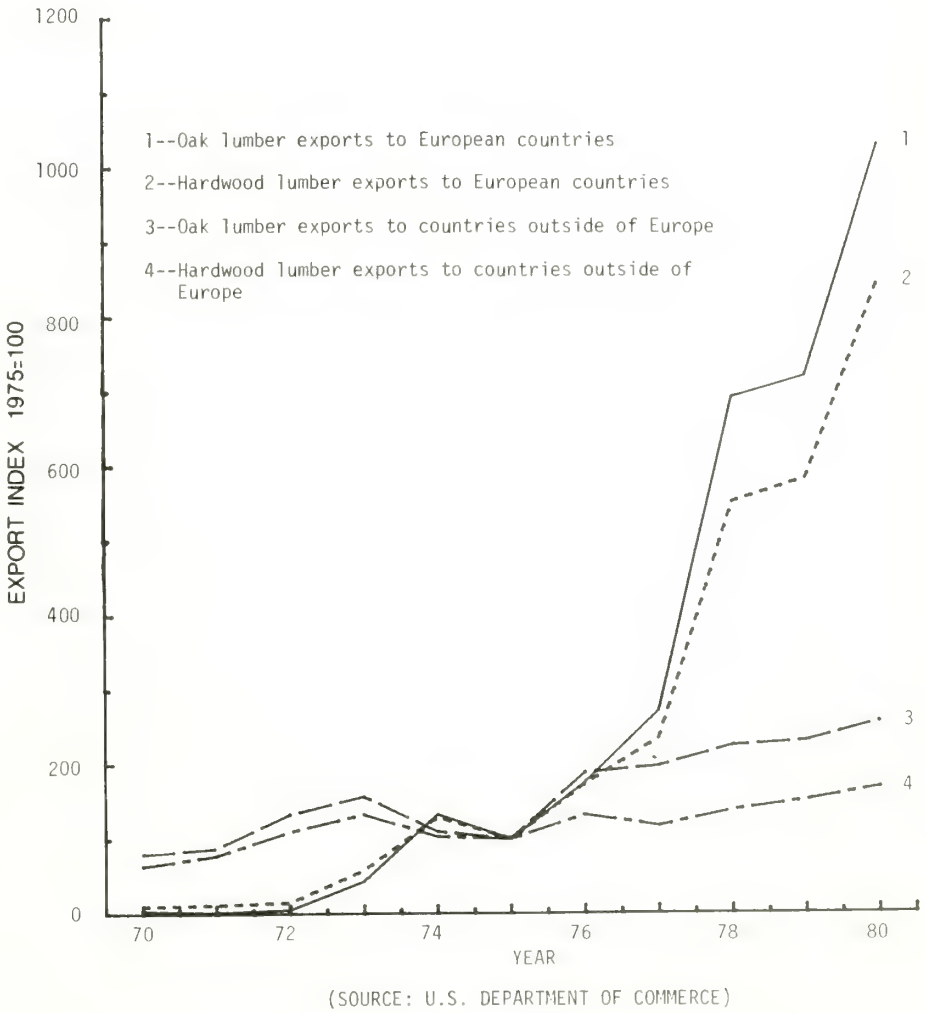

Figure 1.—Indexes of quantities of oak and hardwood lumber exported to European and non-European countries. (Source: U.S. Department of Commerce)

[1] Nominal price is the price that exists in the marketplace. Real price is the nominal price divided by the true rate of inflation. Relative price is nominal price divided by a nominal price of another commodity or commodity group. Relative price may be a reasonable measure of real price if the adjusting index is based on a broad composite of commodities.

Model Development

forces within the domestic hardwood lumber market could also have contributed to these fluctuations. The objective of this paper is to isolate and measure the determinants of oak and hardwood lumber price to assess the impact of exports on prices of oak and hardwood lumber.

Luppold (1982) developed an equation for nominal hardwood lumber price as part of a system of equations depicting hardwood lumber demand, supply, and price. The price equation was estimated using ordinary least squares (OLS) procedures because the hardwood lumber market was assumed to be recursive, with quantity of hardwood lumber demanded being a function of past lumber price, and because the error term associated with the estimated equations was found to be uncorrelated.

The specification of Luppold's (1982) price equation included variables representing past lumber price, quantity of lumber demanded domestically, quantity of lumber exported, and millstocks. Past price was included as a measure of price expectations, domestic demand and exports were included to account for the effects of these demands on price, and millstocks were included to determine the effects of changes in inventories. In this type of model specification, supply does not enter directly into the price equation; but the effects of supply are reflected in changes in inventories. Therefore, the inclusion of the domestic demand and millstock variables accounted for the demand and

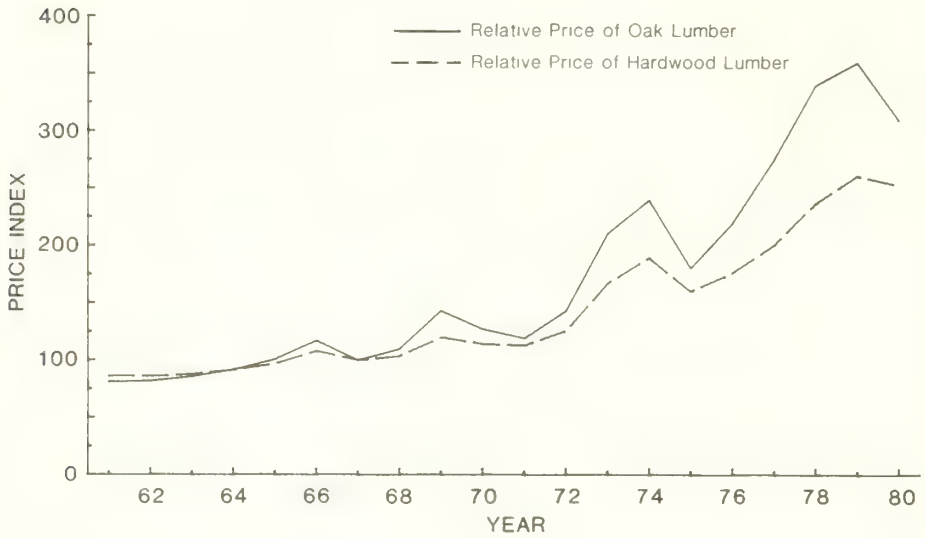

Figure 2.—Indexes of oak and hardwood lumber prices.

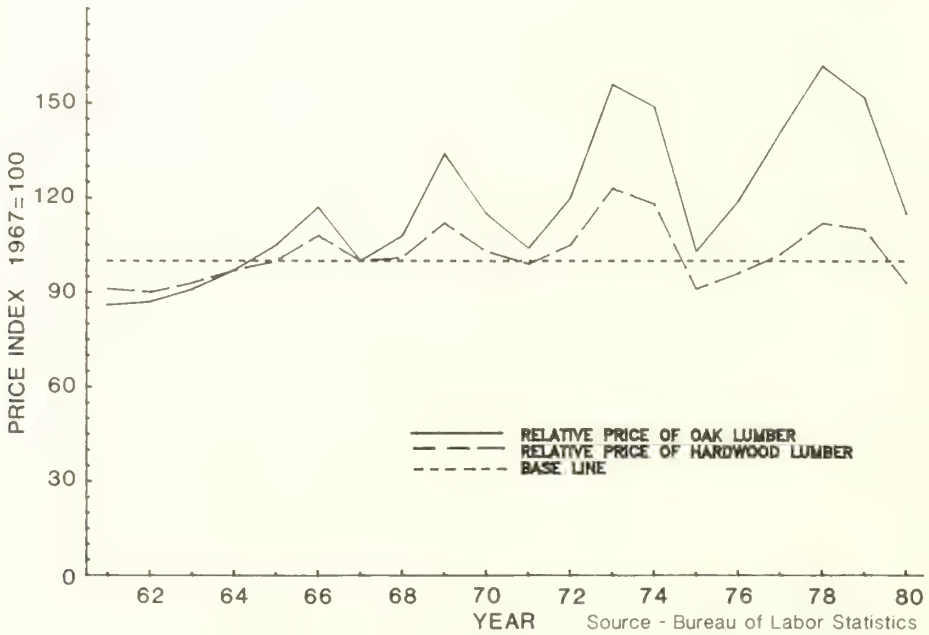

Figure 3.—Indexes of relative prices of oak and hardwood lumber (relative to the price index for all commodities).

Errata Sheet for Research Paper NE-558

Pg. 1, Column 3, 5th line -- should read 1967=100 baseline
instead of 1967-100 baseline

Pg. 4, footnote 2 -- 5th line -- the two little a's should be the
Greek letter delta (∂)

8th line -- the two alphas (α) should be the
Greek letter delta (∂)

10th line -- the two little a's should be the
Greek letter delta (∂)

supply forces in the domestic hardwood market, while the export variable accounted for the demand forces outside the domestic market.

The weakness in Luppold's specification is that one cannot separate the influence of exports from the influence of inflation and expectations of inflation since all followed similar paths. Therefore, the influence of exports could have been over- or underestimated in Luppold's specification. A real-price model or its operational proxy, a relative price model, would resolve this problem. The models to be presented in this paper are relative price models with the price expectation variable.

Another difference between the specification of the current price equations and Luppold's (1982) specification is that European and non-European exports are represented by separate variables. This allows us to separate the effects of European exports from those of exports in general and also to test whether European exports affect domestic lumber price differently from non-European exports. The specific definition of the variable to be included in the hardwood lumber and oak lumber relative price equations is outlined in Table 1.

Table 1.—Dependent variables for the hardwood lumber and oak lumber price equations

Variable	Actual variable used in hardwood lumber price model	Actual variable used in oak lumber price model
Quantity demanded domestically	Quantity of hardwood lumber domestically consumed in current year	Quantity of hardwood lumber domestically consumed multiplied by the proportion of oak lumber produced
Exports to Western Europe	Quantity of hardwood lumber exported to Western European countries	Quantity of oak lumber exported to Western European countries
Exports outside of Western Europe	Quantity of hardwood lumber exported to other than Western European countries	Quantity of oak lumber exported to other than Western European countries
Millstocks (inventories)	Average level of millstocks of hardwood lumber at end of current year and past year	Average level of millstocks of hardwood lumber multiplied by the proportion of oak lumber produced in current year and past year.

Data Base

The data base used in the estimation of the hardwood lumber price equation and the oak lumber price equation extended from 1960 through 1980. All data were obtained or derived from secondary sources.

Indexes for hardwood lumber price, oak lumber price, and the producer price index of all commodities were obtained from U.S. Department of Labor, *Producer Price and Price Indexes.* Since no aggregate oak price representing all grades and species was available through the time period under study, the price of No. 1 Common red oak was used as the dependent variable in the oak price equation.

Quantities of hardwood lumber and of oak lumber exported were obtained from *U.S. Exports, Schedule B, Commodity by Country.* Millstock and lumber production figures were obtained from U.S. Department of Commerce, Bureau of the Census, *Current Industrial Reports: Lumber Production and Mill Stocks.* Quantity of hardwood lumber demanded domestically was derived by subtracting exports and changes in millstocks from production figures.

The quantity of oak lumber demanded and the millstocks of oak lumber were estimated by multiplying the proportion of oak lumber produced by domestic quantity demanded and by millstocks, respectively. The proportion of oak lumber produced was calculated by dividing oak lumber production by total hardwood lumber production.

Model Estimation

The statistically estimated price equations for hardwood lumber and oak lumber are presented in Table 2. Both equations fitted the data relatively well, as indicated by the R^2's and the "t" statistics. The non-intercept variables representing exports to Europe, millstocks, and domestic demand were significant at the 0.10 level or better. The variable representing non-European exports was insignificant in both equations. The Durbin Watson (DW) statistics of both equations fell into the inconclusive range, so the hypothesis of autocorrelation could not be accepted or rejected.

The price equations were estimated by taking the natural logarithms of the independent and dependent variables, then estimating their relationships by OLS procedures. The equations resulting from the transform data are in multiplicative form, and the resulting parameter estimates can be directly interpreted as price flexibilities.[2]

[2] Flexibilities are used in interpreting price equations as elasticities are used to analyze demand and supply equations. Mathematically, a flexibility is the (aP/aQ) (Q/P) where Q represents a quantity and P represents commodity price. This contrasts with the elasticity formula of $\frac{\partial Q}{\partial P}\frac{P}{Q}$. Given the multiplicative form, $P = Q^b$, where b is the estimated parameter, (aP/aQ), $(Q/P) = b\ Q^{b-1}\ (Q/Q^b) = b$.

Table 2.—Ordinary least squares estimates for hardwood and oak lumber price equations (t statistics in parentheses)

Item	Hardwood lumber	Oak lumber
Intercept	4.06*	− 0.066
	(2.32)	(0.141)
Quantity demanded domestically	0.610**	1.44[a]
	(3.50)	(2.51)
Exports to Western Europe	0.017*	0.074**
	(1.52)	(3.41)
Exports outside of Western Europe	− 0.046	− 0.119
	(0.815)	(0.942)
Millstocks	− 0.662**	− 0.931**
	(6.47)	(4.78)
R^2	0.822	0.819
DW	1.31	0.90

** = Significant at the 0.01 level
* = Significant at the 0.05 level
[a] = Significant at the 0.10 level

Analysis

"Price flexibility" is the percentage change in price resulting from a 1-percent change in an independent variable (Tomek and Robinson 1972). Flexibilities have been widely used to analyze agricultural markets in which demand and supply forces are buffered by the existence of a large fluctuating inventory. Although hardwood lumber does not exhibit the seasonal inventory extremes common in the soybean, corn, and wheat markets, millstocks of lumber account for as much as 17 percent of the annual production and can vary by 45 percent in a single year.

Flexibilities can be viewed as inverse elasticities to the extent that the more elastic a demand for a commodity is, the lower its flexibility. Luppold (1984) found that the European demand for oak lumber was quite elastic, and Luppold (1982) found domestic hardwood lumber demand to be near unitary elasticity. These results are supported by the current study, since export demand flexibilities are much smaller than domestic demand flexibilities. Since the non-European export coefficient was insignificant, future use of the term "price flexibility of exports" refers to exports to Western Europe.

The estimated price flexibilities indicate that oak lumber price is affected by changes in domestic demand, millstocks, and exports to a greater degree than is hardwood lumber price. This finding may explain why oak price tended to fluctuate more than hardwood lumber price even during the pre-1973 period when exports were a minor part of the market. The increased divergence between oak lumber and hardwood lumber price fluctuations since 1973 (Figs. 2 and 3) probably results from the facts that (1) changes in oak exports affect oak price more than changes in hardwood exports affect hardwood price, and (2) changes in oak exports to Europe have been greater than changes in hardwood lumber exports.

Another interesting fact demonstrated by the estimated price flexibilities is that a 1-percent change in domestic demand or millstocks has a much larger influence on hardwood lumber and oak lumber prices than a 1-percent change in exports. In the case of oak lumber price, exports would have to increase by 19.5 percent to have the same impact as a 1-percent change in domestic demand and by 12.6 percent to have the same impact as a 1-percent change in millstocks. During the 1972-to-1980 period, yearly changes in domestic demand averaged 6 percent, yearly changes in millstocks averaged 12 percent, and yearly changes in exports averaged 50 percent. Analysis based on these 1972-1980 average yearly changes shows that changes in domestic demand affected oak lumber price 2.3 times as much as changes in exports and changes in millstocks affected oak lumber price 3 times as much as changes in exports. Similarly, changes in domestic demand affected hardwood lumber price 5.2 times as much as changes in exports, and changes in millstocks affected price 10.1 times as much as changes in exports.

The above analysis should not be interpreted as indicating that exports have little discernible effect on oak and hardwood lumber prices. During the late 1970's, when domestic demand was increasing and millstocks were decreasing, increased levels of exports helped push lumber prices up even further. On the other hand, during 1979 and 1980, when domestic demand was decreasing and inventories were increasing, increases in exports helped moderate the drops in hardwood lumber and oak lumber prices. However, since 1980, changes in export demand have moderated; therefore, the effect of exports on hardwood lumber prices has moderated.

Conclusions

Increases in exports of hardwood and oak lumber to Europe did contribute to the increases in the nominal and relative prices of these commodities during the 1970's. Exports affected oak lumber price more than hardwood lumber price because: (1) The increase in oak exports to Europe was 20 percent greater than the exports of all hardwood lumber to Europe, and (2) a 1-percent change in exports affects oak price 3.3 times as much as a 1-percent change in hardwood lumber affects hardwood lumber price. However, changes in domestic demand and millstocks have had more influence on hardwood lumber and oak lumber prices than changes in exports. Furthermore, changes in exports of hardwood lumber have leveled during the last 5 years. Therefore, exports of hardwood and oak lumber can be thought of as contributing to the formation of hardwood lumber prices, but domestic demand and level of millstocks have been and will be the major factors that influence domestic hardwood lumber prices.

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Econometric equations were estimated to determine the effects of domestic foreign hardwood lumber demands on oak and hardwood lumber prices. Oak price seemed to be more sensitive to changes in exports than overall hardwood lumber price. However, the main determinants of hardwood lumber and oak lumber prices were found to be domestic demand and millstock levels.

ODC 722.4

Keywords: Economics; demand; oak

*U.S. GOVERNMENT PRINTING OFFICE: 1985-

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Research Paper
NE-559

1985

Low-Cost Opportunity for Small-Scale Manufacture of Hardwood Blanks

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Philip A. Araman

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Manuscript received for publication
6 August 1984

Abstract

We analyzed the manufacture of standard-size hardwood blanks from lumber on a relatively small scale by conventional processing. Requiring an investment of just over $200,000, the conventional mill can process 500 M bf (thousand board feet) of kiln-dried lumber annually. The study focused on the economics associated with manufacture of blanks from four species—northern red oak, black cherry, hard maple, and yellow-poplar. Assuming a tax rate of 46 percent, returns ranged from 31 percent for hard maple to 38 percent for yellow-poplar. Plots were developed relating raw material input cost to blank prices necessary to achieve specified levels of return.

The blanks investment seems suited to someone wishing to enter the wood business on a small scale, to sawmill operators wishing to upgrade and expand their product offering, and to small furniture and cabinet manufacturers wanting more control of their raw material situation.

Introduction

All those in the hardwood lumber business recognize the advantages and ready market for high-quality hardwood lumber. However, nearly 87 percent of all sawlog timber is Log Grade 2 and below[1] (McLintock 1983). As a result, at least 60 percent of the hardwood lumber produced is grade No. 2 Common or lower—grades normally passed over in the manufacture of furniture and cabinet dimension stock. Considerable benefit could result from upgrading some of this low- and medium-grade material. In this paper we discuss a low-capital-outlay manufacturing facility in which medium (No. 1 Common) and low (No. 2 Common) grade kiln-dried lumber is used to make standard-size blanks (Araman 1983)—a product developed for furniture and cabinet manufacturers.

Previously we designed and described the operation of a full-scale hardwood blanks mill (Araman and Hansen 1983) that is based on conventional technology. This mill could profitably convert a log-run mix of northern red oak lumber into standard-size hardwood blanks. The mill described required an initial investment of about $3 million (1980 dollars) to process 16 M bf (thousand board feet) of lumber into 9.6 M bf of edge-glued blanks per shift. By contrast, this study examines the manufacturing of blanks on a much smaller scale, and looks at the manufacture of four species rather than one. Also, a schedule of blank prices needed to achieve specific levels of return for a broad range of raw material input cost has been developed.

[1] USDA Forest Service grade rules.

Processing System

Table 1 includes a detailed description of equipment and building costs for the facility (Fig. 1) in our analysis. Although other designs are possible, our design relies on conventional processing techniques, including crosscutting first followed by random-width ripping. The estimated initial capital cost for the plant facility, including 3 acres of land, is just over $200,000.

The plant is assumed to operate one shift, 250 days per year, processing 500 M bf of lumber into 300 M ft² (4/4 basis) of red oak, black cherry, or hard maple blanks, or 325 M ft² (4/4 basis) of yellow-poplar blanks annually.

The plant employs six people at a cost of $84,000 annually. This assumes an hourly rate of $7—$5.40 in wages plus $1.60 in mandatory fringe benefits. In addition, an administrative and management staff of two is allocated $70,000 annually for salaries and office expenses. Another $20,000 covers annual costs for utilities, supplies, and maintenance. Selling expenses were set equal to 1 percent of gross revenue.

Table 1.—Facility requirements and estimated costs for the standard-size blanks plant

Facility requirements	Cost[a]
	Dollars
Forklift (2 ton)	11,000
Crosscut saw with table	9,900
Ripsaw with laser guide light	17,600
Abrasive planer (37-inch top machine)	27,500
Clamp carrier (8-1/2 feet wide, 20 sections)	16,390
Glue pump and applicator	5,060
Factory trucks (25)	9,240
Compressed air unit	5,500
Dust system	5,500
Office equipment and furnishings	11,000
Land (3 acres)	33,000
Building (40 by 85 feet, preengineered, $15.40/ft²	52,360
Total	204,050

[a] 1980 prices increased by 10 percent.

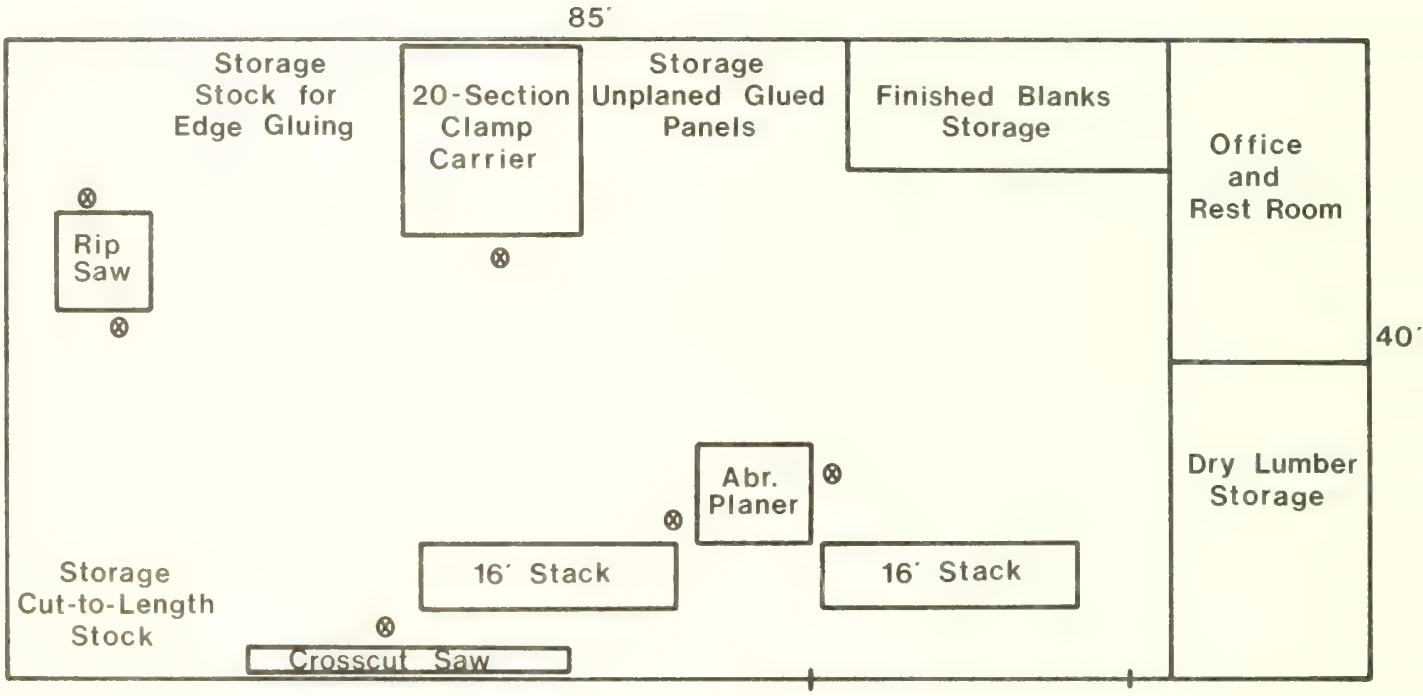

Figure 1.—The blanks manufacturing facility.

Lumber is kiln dried and either purchased delivered or transferred at market price from another division of an ongoing firm and stored for cut-up in the rough mill. Lumber is made into edge-glued panels by a conventional rough plane, crosscut-rip-salvage rough mill. After planing, up to 12 standard lengths are cut at the crosscut saw. Random-width cuttings are ripped from the cut-to-length boards. Pieces containing defects are salvage crosscut into shorter standard length cuttings. Clear cuttings are matched for color and grain, put into panel sets, and edge-glued. After gluing, blanks are rough planed and placed into inventory. Blanks are sold in standard sizes or they can be remanufactured into specific size parts.

Raw Material and Product Yields

The following are raw material and yield assumptions used in the analyses.

- Only 4/4 lumber is used.
- The grade mix of lumber used in manufacturing blanks consists of 60 percent No. 1 Common and 40 percent No. 2 or No. 2A Common.
- Costs for red oak, black cherry, hard maple, and yellow-poplar were obtained for 4/4 No. 1 Common and No. 2 or No. 2A Common from the April 7, 1984, *Hardwood Market Report*. Additional charges were added for kiln drying and transportation in deriving input cost per M bf at the mill.

Species	*Prices* No. 1 C	No. 2C or 2AC	*Weighted average*	*Kiln costs*	*Trans-portation*	*Total*
			Dollars/M bf			
Red oak	615	255	470	100	40	610
Black cherry	605	305	485	75	40	600
Hard maple	342	215	290	100	40	430
Yellow-poplar	260	170	225	65	40	330

- A 60-percent yield in blanks was assumed for red oak, black cherry, and hard maple. Yellow-poplar was assumed to have a 65-percent yield. Yield assumptions were calculated using FPL-118 (Englerth and Schumann 1966) yield tables, and by adjusting these to allow for a 6-percent lumber shrinkage, a 60/40 lumber grade mix, and standard-blank size requirements. These requirements were determined after an extensive survey of manufacturers of solid furniture and kitchen cabinets (Araman et al. 1982). Although thousands of different part sizes were reported in the survey, it was found that relatively few standard blank sizes could meet the industries' varied requirements.

- The standard blanks are C1F (clear-one-face), 7/8 inch thick, and 26 inches wide (edge-glued) with lengths predominantly between 15 and 40 inches, though some are as long as 100 inches. Market price assumptions for blanks were developed from estimates of edge-glued product prices obtained from conversation with dimension manufacturers since market price reports for panel products are not available. The prices used in this analysis were:

Species	*Dollars/M ft²*
Red oak	2300
Black cherry	2300
Hard maple	1900
Yellow-poplar	1700

Economics

The economic discussion focuses on construction of the net present value (NPV) and internal rate of return (IRR) discounted cash flow measures. These measures best account for the relationship among cash flows (that is, the initial investment, operating costs, and revenues) throughout the entire life of the investment, giving explicit recognition to the timing of cash flows, foregone opportunities, and capital costs.

Table 2 provides summaries of the cash flows expected during the

Table 2.—Cash flow summaries for red oak, black cherry, hard maple, and yellow-poplar (tax rates of 30 and 46 percent)

Year	Facilities and working capital investment	Gross revenues	Operating costs	Depreciation	Net after-tax cash flow 30%	Net after-tax cash flow 46%
			Thousands of dollars			
			RED OAK			
0	243				−243	−243
1	18	345	330	22	− 1	0
2		690	486	33	153	126
3		690	486	32	152	125
4		690	486	27	151	123
5		690	486	27	151	122
6		690	486	4	144	112
7-9		690	486	3	144	112
10		690	486	3	248	216
			BLACK CHERRY			
0	243				−243	−243
1	18	345	327	22	1	2
2		690	481	33	156	128
3		690	481	32	156	127
4		690	481	27	155	125
5		690	481	27	154	125
6		690	481	4	147	115
7-9		690	481	3	147	114
10		690	481	3	251	218
			HARD MAPLE			
0	238				−238	−238
1	13	285	284	22	− 6	− 2
2		570	395	33	133	110
3		570	395	32	132	109
4-5		570	395	27	131	107
6		570	395	4	124	96
7-9		570	395	3	124	96
10		570	395	3	217	190
			YELLOW-POPLAR			
0	235				−235	−235
1	10	275	259	22	8	9
2		553	345	33	156	128
3		553	345	32	155	127
4-5		553	345	27	154	125
6		553	345	4	147	114
7-9		553	345	3	147	114
10		553	345	3	234	201

10-year investment period for each of the four species. In all examples, full production is not achieved until the second year of operation, so revenues in year 1 are half those thereafter. Except for raw material costs and selling expenses, however, first-year costs equal those under full production.

The derivation of the net after-tax cash flows in most years is straightforward. To begin, operating costs and depreciation were subtracted from revenues, taxes were computed, and then depreciation was added to the after-tax income. However, there are instances where other considerations affect the net after-tax cash flows. First, as the plant moves to full production in year 2, additional working capital is required. Harpole's (1978) program increases working capital automatically using the relationship between initial working capital outlays and operating costs. Second, the program allows for complete writeoff of depreciation in the year it occurs whether or not there is sufficient income from the project itself. In such instances, it is implicitly assumed that there is additional income for the investor, allowing the complete and immediate write-off to occur. This treatment enhances the net after-tax cash flow only to the extent of the tax benefit derived from depreciation. Third, proceeds from the assumed sale of land and from real assets in an amount equal to their remaining book value, plus the return of working capital, are added to the operating cash flows at the end of year 10.

Depreciation allowances were calculated using Accelerated Cost Recovery System schedules. Accordingly, building expenditures were depreciated over 15 years; all equipment, with the exception of 25 factory trucks, in 5 years; and the 25 factory trucks in 3 years. In keeping with general practice, assets not fully depreciated in 10 years are assumed to be sold at the end of the tenth year at a price equal to their remaining book value. Investment tax credits were not considered.

In discounted cash flow analyses, initial working capital outlays are a part of the initial investment. Subsequent outlays are thought to derive from after-tax cash flows in the year preceding their use. These outlays are required to cover expenditures for raw material, work in process, finished goods inventories, and to cover sales where credit terms are extended to the buyer. We allow for working capital to cover approximately 10 days' inventory of raw material plus 25 days' output of finished product. Working capital requirements vary in relation to the value of the species being manufactured.

While individual investor circumstances, capital costs, tax rates, and alternative investment opportunities will ultimately dictate investment decisions, our results indicate that the blanks manufacturing option for small-scale investment should be of considerable interest. Assuming that the corporate maximum tax rate of 46 percent applies, investment performance after taxes as measured by the IRR ranged from a low of 31 percent for the manufacture of hard maple blanks to a high of 38 percent for the manufacture of yellow-poplar blanks. The NPV, given a discount rate of 15 percent, ranged from $213,000 to $298,000 for hard maple and yellow-poplar, respectively.

For those whose effective tax rate lies below 46 percent, the returns are even better. For instance, given a tax rate of 30 percent, the IRR ranged from 37 percent to 45 percent. Corresponding improvement in the NPV also is evident. Table 3 contains performance measures for all species assuming effective tax rates of 46 and 30 percent.

Table 3.—Internal rate of return (IRR) and net present value (NPV) for blanks manufacture of selected species assuming effective tax rates of 46 and 30 percent

Species	Tax rate			
	46 percent		30 percent	
	IRR	NPV	IRR	NPV
	Percent	*Thousands of dollars*	*Percent*	*Thousands of dollars*
Red oak	35	277	42	399
Black cherry	36	290	43	415
Hard maple	31	213	37	314
Yellow-poplar	38	298	45	422

Raw Material Cost/Blank Price Relationship

To this point our efforts have focused on evaluating performance for specific species. While investment seems quite promising, these analyses have failed to provide information as to the potential return for still other species or for changes in the relationship between the cost and price for the species already investigated. Recognizing this, we have plotted "generic" cost/price relationships, for 20-, 30-, and 40-percent return on investment. Plots have been constructed for tax rates of 30 and 46 percent (Figs. 2-3). The cost/price plots account for raw material costs from $200/M bf to $1,000/M bf and for blank prices ranging from about $1,200/M ft² to about $3,200/M ft².

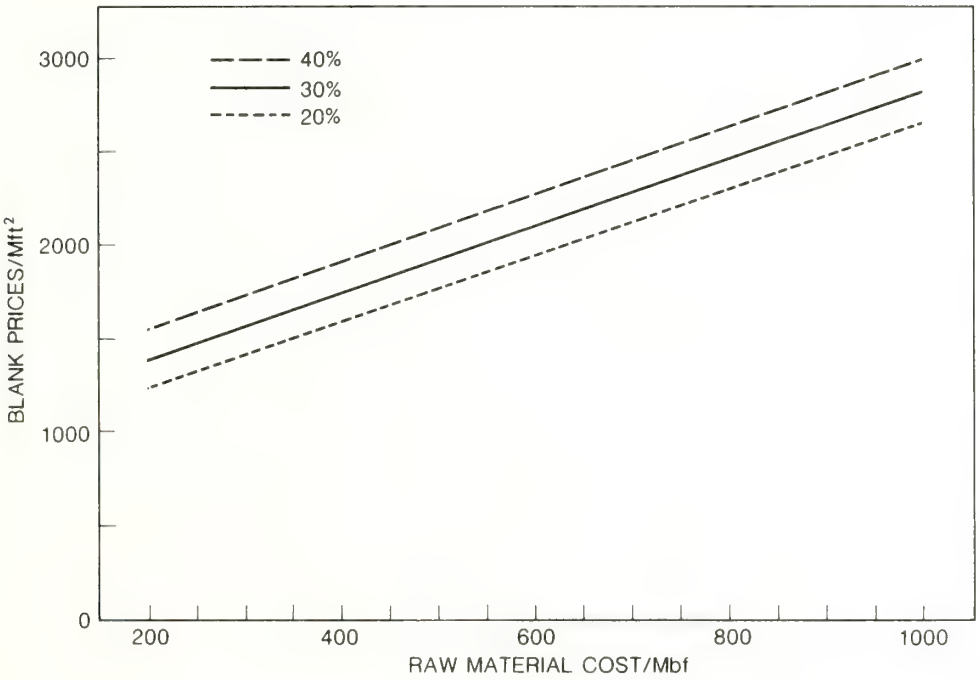

Figure 2.—Cost/price relationship for a 20-, 30-, and 40-percent return on investment (tax rate = 30 percent).

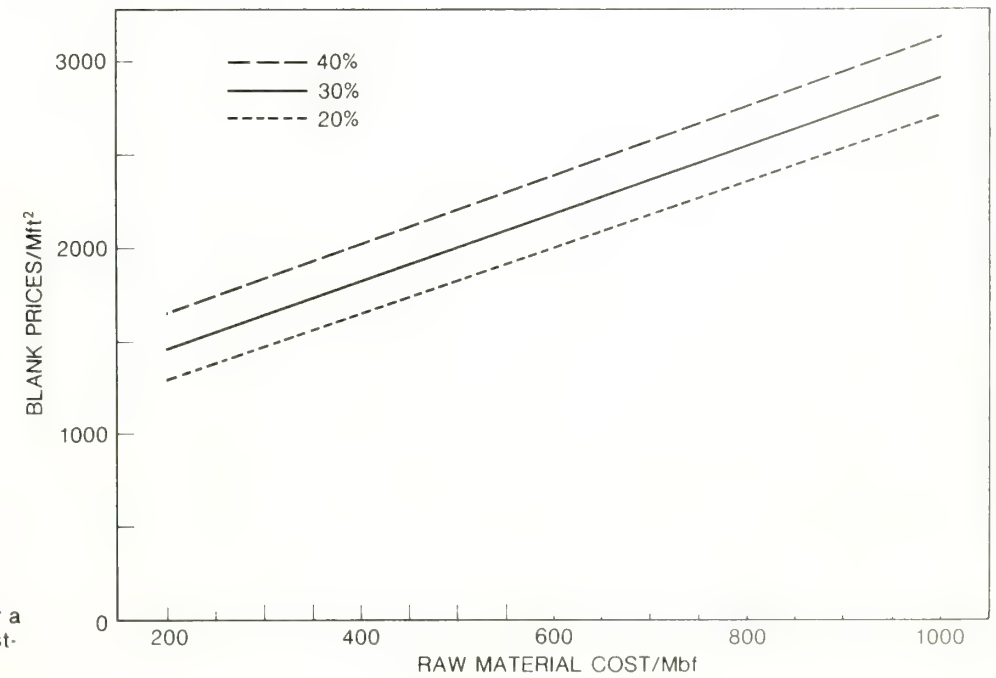

Figure 3.—Cost/price relationship for a 20-, 30-, and 40-percent return on investment (tax rate = 46 percent).

These plots can be used to evaluate the price of blanks necessary to earn a particular return given a certain cost for lumber. For example, using Figure 3, a 20-percent return could be earned given an input material cost of $600 if blanks were priced at $2,000/M ft². To achieve a 40-percent return, the price would need to be increased about $400 to about $2,400/M ft².

The plots can be used in still another situation. That is, where the price for blanks is given and an investor wishes to know what he can pay for raw material and still achieve a desired level of return. Returning to Figure 3, it can be seen that a blanks' price of $2,600/M ft² would allow about $710/M bf to be paid for raw material if a return of 40 percent is to be made. If a 20-percent return were acceptable, the price paid for raw material could be increased about $230/M bf to $940/M bf.

Discussion and Conclusion

While the plant described would be attractive in allowing someone not otherwise in the wood business to enter the wood business on a small scale and then possibly expand, it seems particularly suited for investment by sawmill operators. Small furniture and cabinet manufacturers, too, would realize several benefits by including blanks manufacture in their operations.

Sawmillers would benefit by having a means to use some of their medium- and low-grade lumber (No. 1 and No. 2 Common) in the manufacture of a higher valued product. Too, they would put more value added into their expanded product offering. Since FAS (Firsts and Seconds) or Select grade material is not needed, these grades would still be available to command the highest premium the market has to offer.

Small furniture and cabinet manufacturers either producing or purchasing blanks would be better able to control their raw material situation. Since production often is on a job-shop basis, few parts of any one size are ordinarily required at one time. Because panels can be inventoried and parts cut to size almost immediately, blanks seem ideally suited to the job-shop environment. Additionally, this group would enjoy the same advantages enjoyed by the sawmiller in being able to use more No. 2 Common than is customary in the production of fine furniture.

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Hansen, Bruce G.; Araman, Philip A. **Low-cost opportunity for small-scale manufacture of hardwood blanks.** Res. Pap. NE-559. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1985. 6 p.

Discusses the economics associated with the small-scale manufacture of blanks from four species—red oak, black cherry, hard maple, and yellow-poplar. Assuming a tax rate of 46 percent, returns ranged from 31 percent for hard maple to 38 percent for yellow-poplar. Plots were developed relating raw material input cost to blank prices necessary to achieve specified levels of return.

ODC: 672: 832.1: 836.1

Keywords: Sawmill, furniture dimension, investment analysis, discounted cash flow

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Research Paper
NE-560

1985

Photographic Guide of Selected External Defect Indicators and Associated Internal Defects in Black Cherry

Everette D. Rast

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PUBLIC

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Manuscript received for publication 3 October 1984

Abstract

To properly classify or grade logs or trees, one must be able to correctly identify defect indicators and assess the effect of the underlying defect on possible end products. This guide aids the individual in identifying the surface defect indicator and also shows the progressive stages of the defect throughout its development for black cherry. It illustrates and describes seven types of external defect indicators and associated defects that are particularly difficult to evaluate.

Introduction

This photographic guide on black cherry is the second in a series to aid in the understanding of the relationship between exterior defect indicators and the underlying defect. This study, like the previous one on northern red oak (Rast 1982), was conducted at a veneer slicing plant which enabled us to photograph defect characteristics at intervals of 1/32 of an inch (one sheet of veneer).

Procedure

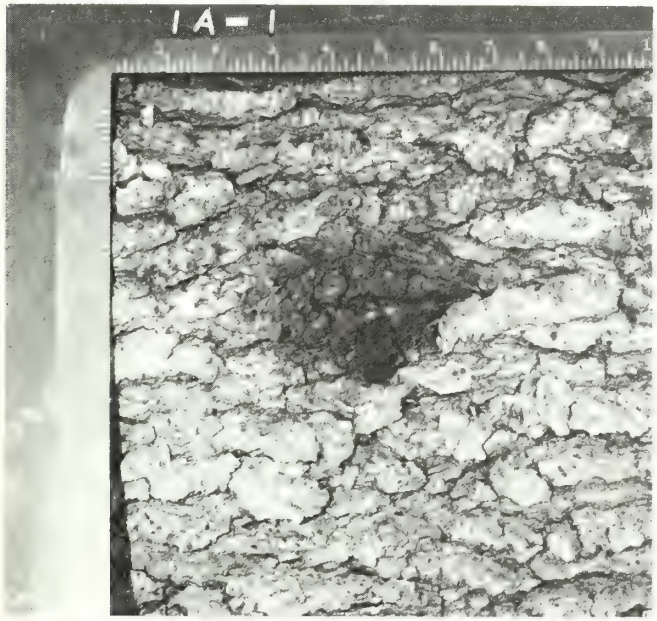
The only procedural change from the 1982 study was that these logs were selected and photographed in the woods. They came from an almost pure stand of black cherry in north central Pennsylvania. The defect indicators reported in this publication are gum lesion; suppressed bud; suppressed bud cluster; light, medium, and heavy bark distortions; sound and unsound wounds; seam; and burl.

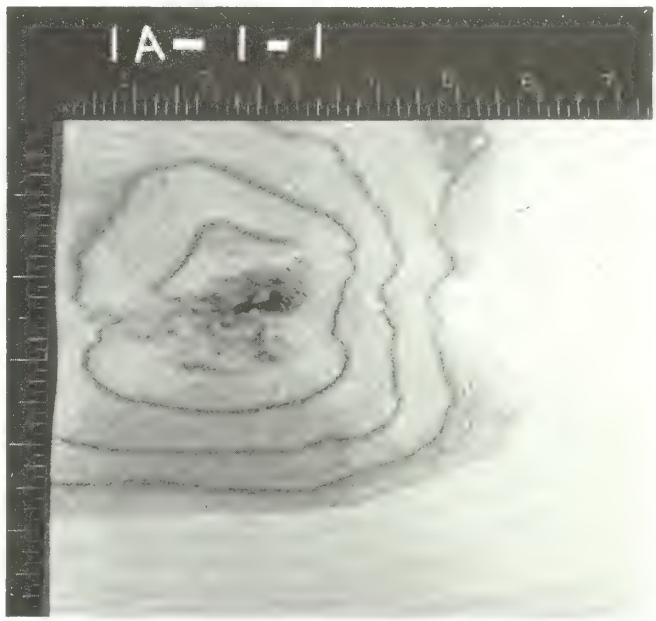
Discussion of Defects

We feel that the selected defect indicators are often difficult to evaluate in terms of their effect on end-product quality. Graders normally have little difficulty recognizing and evaluating the obvious grading defects such as limbs, holes, forks, bulges, or butt scars.

The descriptions listed below the photo of the defect indicator (see Fig. 1) describe its size in terms of

Figure 1.—Gum lesions and associated internal defects.





Defect size ..... 3 x 2 inches
Log diameter ..... 18.6 inches
Log diameter at defect ..... 19.9 inches
Flitch thickness at defect ..... 8.9 inches
Slab + round-up thickness at defect ... 1.3 inches
Log position ..... butt log

Depth below—

Log surface	First sheet of veneer
1.3 inches	0.0 inches

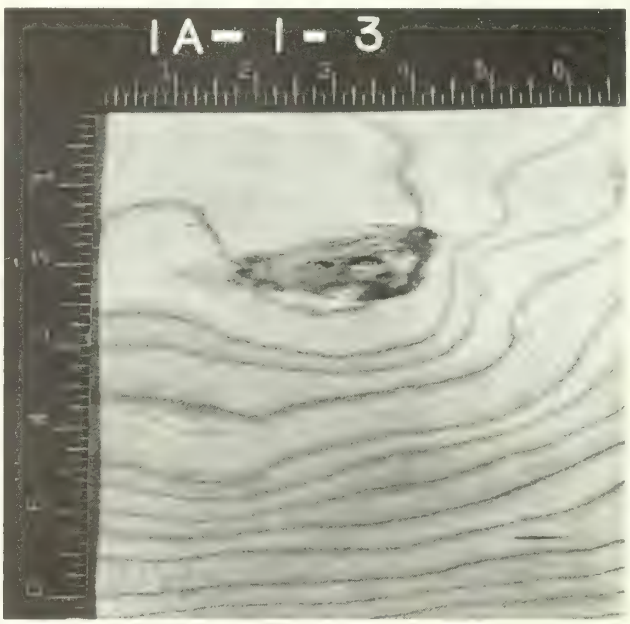
length (along the grain), width (across the grain), and height (above the normal bark surface); log diameter, inside-the-bark small end; log diameter, inside-the-bark at the defect; flitch thickness at the defect; slab plus round-up thickness at the defect; and log position. The information listed under the interior defect (see Fig. 1) indicates distance below the log surface (inside-the-bark) as well as the distance from the first slice of veneer to that particular photographed defect. The last photograph in each defect series also lists cumulative veneer thickness, which is the distance from the initial slice of useable veneer to the last slice of veneer. A point of interest is that the National Hardwood Lumber Association grading rules on black cherry allows small knots or their equivalent not exceeding 1/8 inch in diameter in the cuttings (NHLA 1982).

Gum Lesion

Gum lesions (Fig. 1) appear as slightly darker than normal bark to an almost black area on the already reddish bark of black cherry. Clear to amber-colored exudate is almost always present on the bark surface. Gummosis, the production of this exudate, can result from many causes such as peach tree borer, wounding, bacteria, fungi or even poorly aerated soils (Boyce 1948, Esau 1965). If only gum exudate is present, the defect depth is seldom great, but if the bark appears discolored, the gum and some grain distortion usually extend into the high-quality wood.

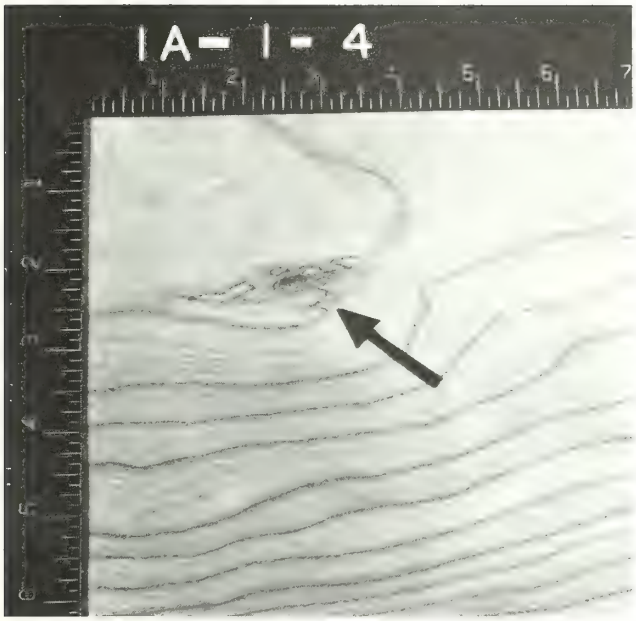
Depth below—

Log surface	First sheet of veneer
1.8 inches	0.5 inches



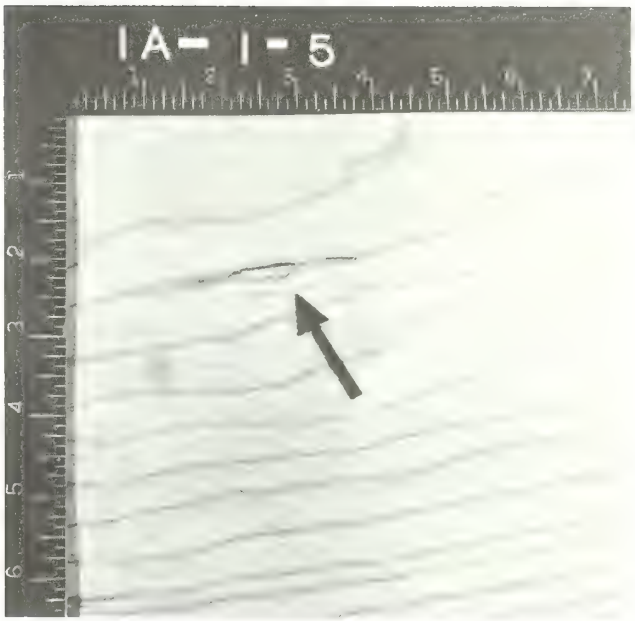
Depth below—

Log surface	First sheet of veneer
2.3 inches	1.0 inches



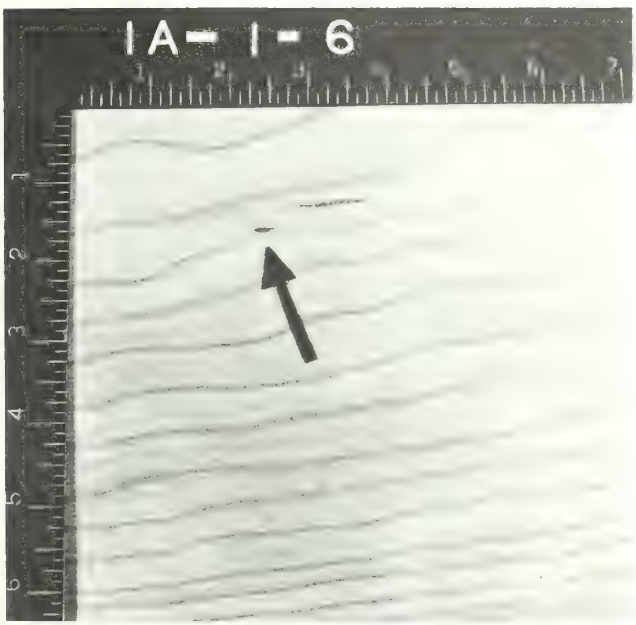
Depth below--

Log surface	First sheet of veneer
2.8 inches	1.5 inches



Depth below--

Log surface	First sheet of veneer
3.3 inches	2.0 inches



Depth below--

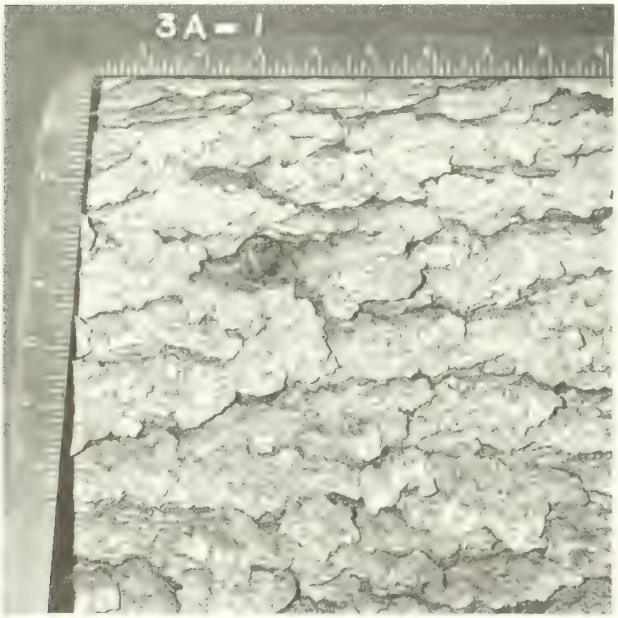
Log surface	First sheet of veneer
3.6 inches	2.2 inches

Total veneer thickness--6.9 inches

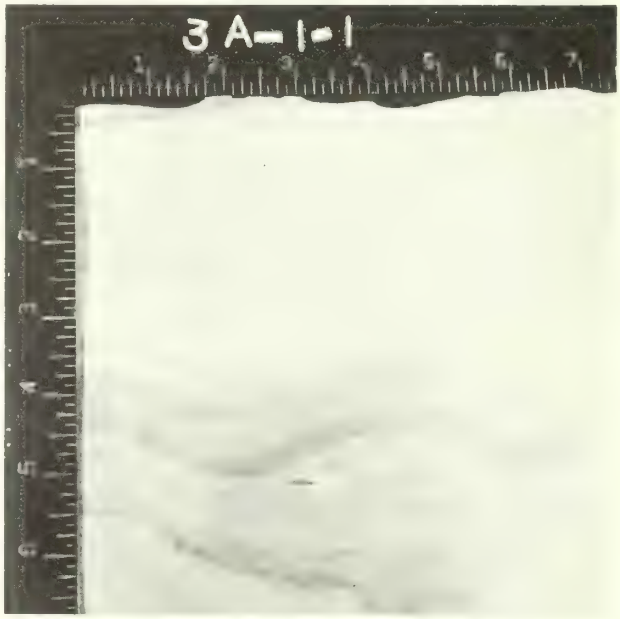
Suppressed Buds

Suppressed buds (commonly referred to as adventitious buds or dormant buds) can persist for many years as just a bud trace (Kormanik 1969), yet never become an epicormic branch (Fig. 2). However, these buds can sprout suddenly after a thinning, or when attacked by insects or infected by disease. Figure 3 shows a cross-section of a log (17.5 inches inside-the-bark) that was sawn right through several of these buds. Each of the bud traces goes from the bark to the pith, with little or no exterior indication that they existed.

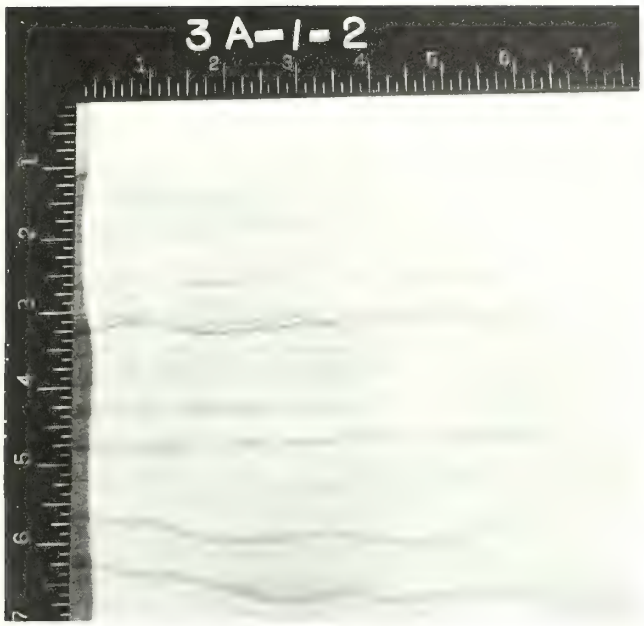
Figure 2.—Suppressed buds and associated internal defects.



Defect size ..... 1/2 x 1/2 x 1/2 inch
Log diameter ..... 18.3 inches
Log diameter at defect ..... 18.9 inches
Flitch thickness at defect ..... 8.7 inches
Slab + round-up thickness at defect ... 1.5 inches
Log position ..... butt log

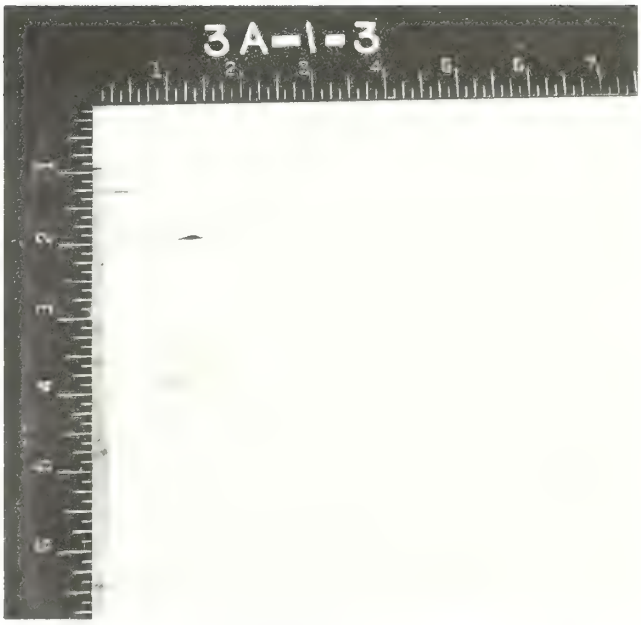


Depth below—	
Log surface	First sheet of veneer
1.5 inches	0.0 inches



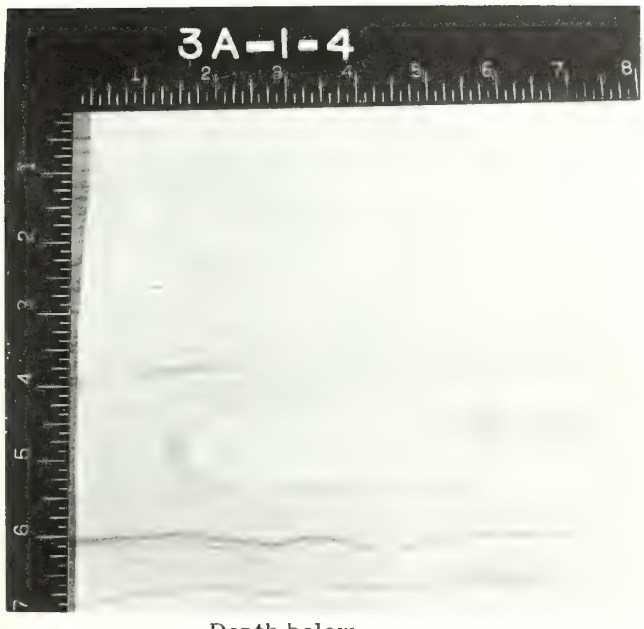
Depth below—

Log surface	First sheet of veneer
4.5 inches	3.0 inches



Depth below—

Log surface	First sheet of veneer
6.5 inches	5.0 inches



Depth below—

Log surface	First sheet of veneer
8.0 inches	6.5 inches

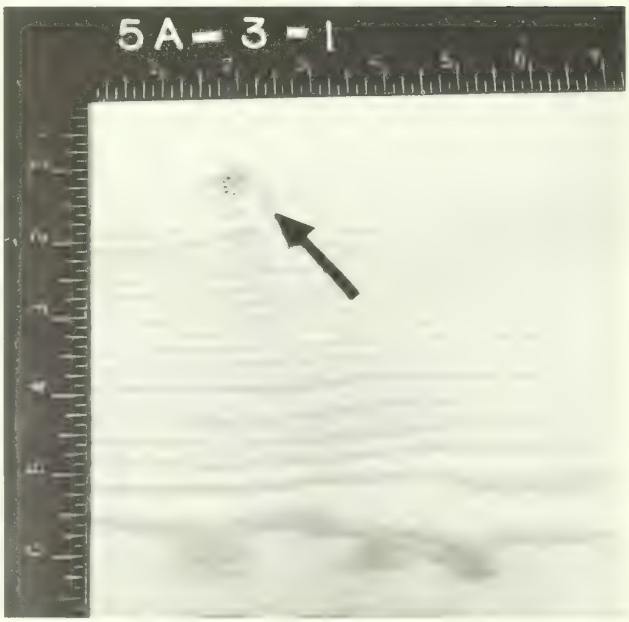
Total veneer thickness--6.7 inches

Figure 3.—Cross-sectional view of log showing bud traces of suppressed buds.

Suppressed Bud Cluster

The major differences between a single bud (or only 2 or 3 buds) and a bud cluster are the size of the defect indicator, evidence of concentric rings around the indicator, and the clustering of numerous knots that can be seen in the wood. Figure 4 shows both the concentric rings around the defect indicator on the bark surface and the many adventitious knots in the underlying wood.

Figure 4.—Suppressed bud cluster and associated internal defects.

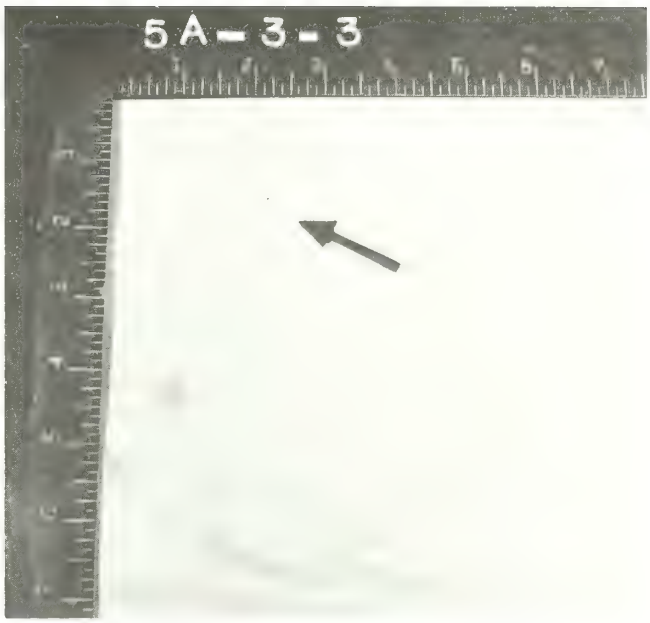


Defect size	1 1/2 x 1 x 1 inches
Log diameter	15.6 inches
Log diameter at defect	15.8 inches
Flitch thickness at defect	6.6 inches
Slab + round-up thickness at defect	2.4 inches
Log position	upper log

Depth below—	
Log surface	First sheet of veneer
2.4 inches	0.0 inches

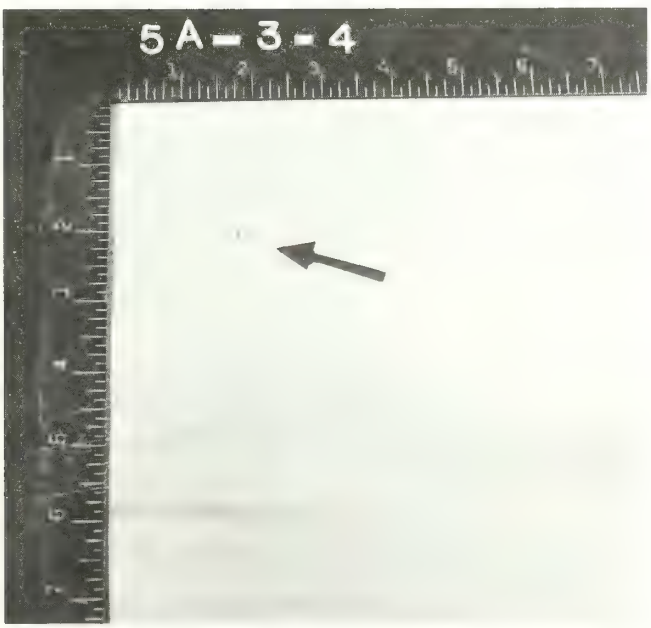
Depth below—

Log surface	First sheet of veneer
4.4 inches	2.0 inches



Depth below—

Log surface	First sheet of veneer
5.4 inches	3.0 inches



Depth below—

Log surface	First sheet of veneer
5.9 inches	3.5 inches

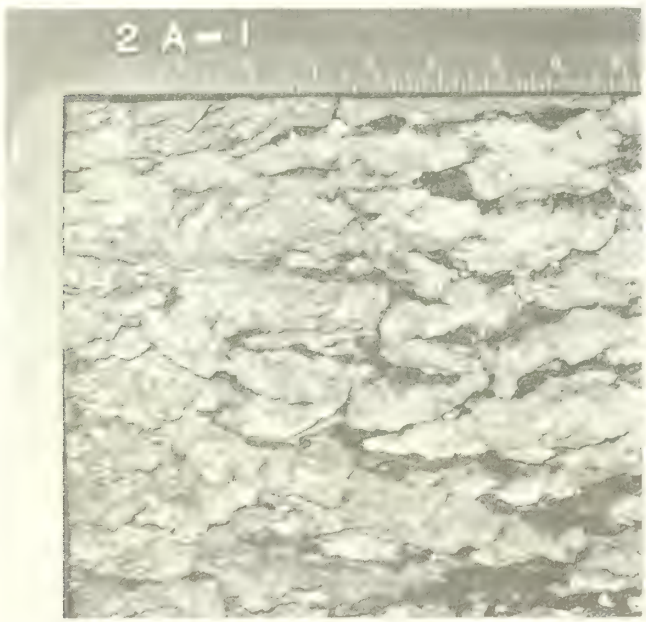
Total veneer thickness--3.7 inches

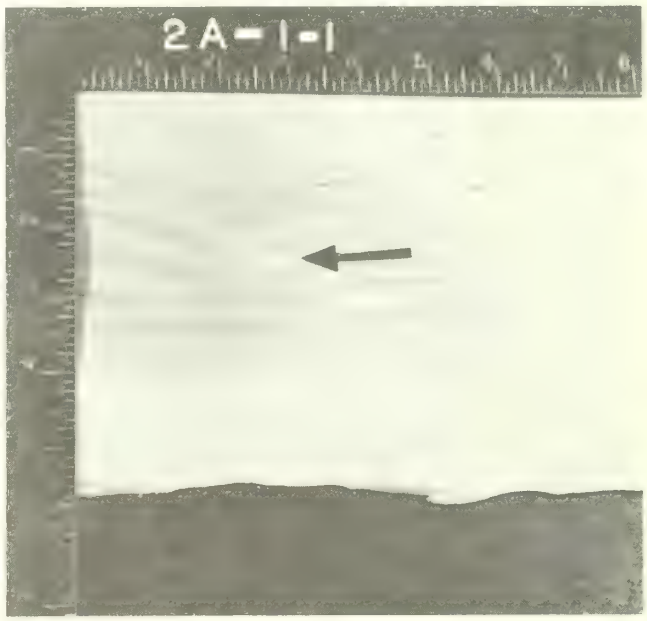
Bark Distortions

Bark distortions—those that are flush with the bark--are subdivided into three categories: light, medium, and heavy bark distortions. A light bark distortion (Fig. 5) shows only a slight amount of curvature in the surrounding bark plates, and the bark pattern shows only slight variance from normal. Because of these features, light bark distortions are very inconspicuous and often overlooked. Medium bark distortions (Fig. 6) show more signs of the concentric circles, but they are broken by flat bark plates or regular bark patterns. Also, there is usually a well-defined break in the bark pattern in the center of the defect indicator. Heavy bark distortions (Fig. 7) are normally identified by the characteristic pattern of concentric circles encompassing the defect indicator. Often in black cherry these rings are concentrated on one side of the defect indicator.

All bark distortions will result in some product degrade, but the amount of degrade will decrease as the depth to the initial defect below the log surface increases. For these bark distortions, if we adjusted for log diameter, then the depth below the log surface to the first sign of the defect would be 5-1/2 inches, 3-1/2 inches, and less than 1/2 inch, respectively.

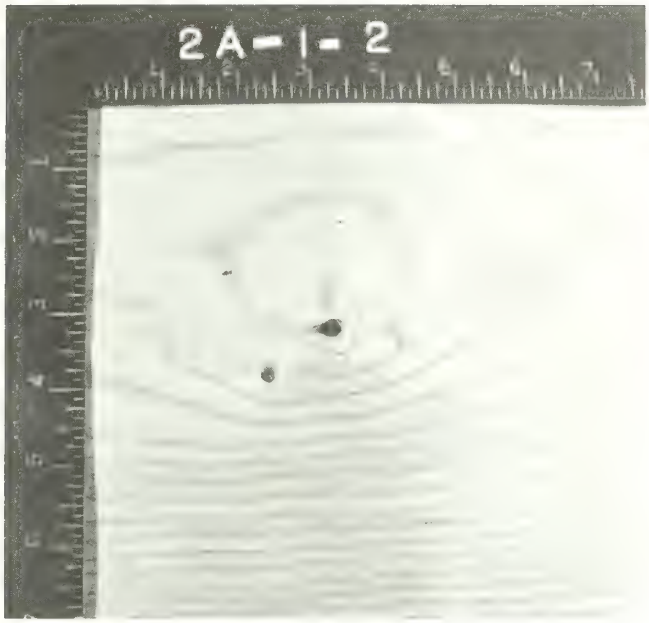
Figure 5.--Light bark distortion and associated internal defects.





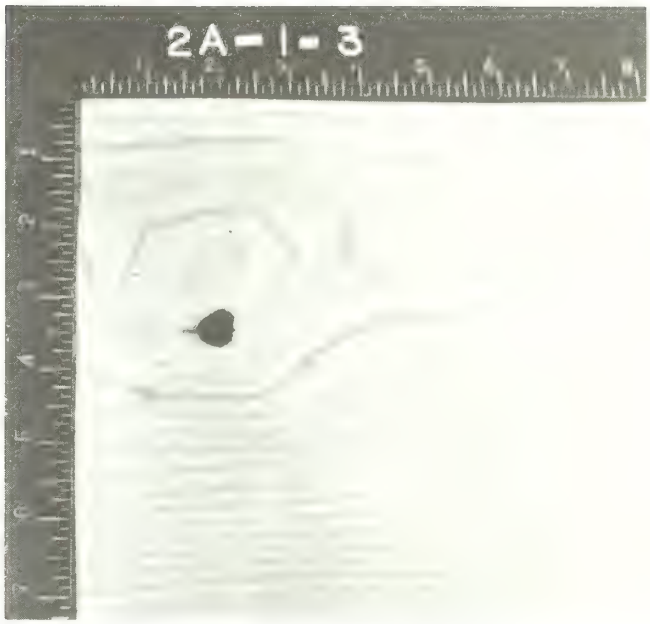
Defect size	2 x 2 inches
Log diameter	17.5 inches
Log diameter at defect	18.1 inches
Flitch thickness at defect	7.2 inches
Slab + round-up thickness at defect	2.1 inches
Log position	upper log

Depth below--	
Log surface	First sheet of veneer
2.6 inches	0.5 inches



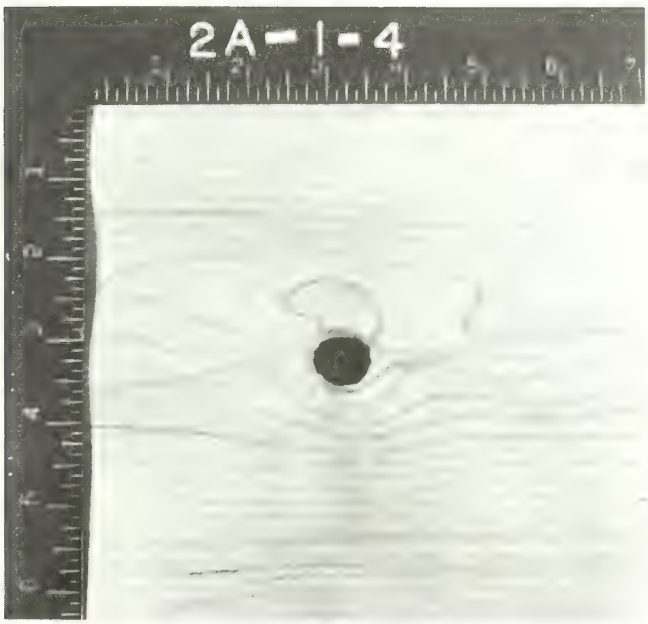
Depth below—

Log surface	First sheet of veneer
4.1 inches	2.0 inches



Depth below—

Log surface	First sheet of veneer
4.6 inches	2.5 inches



Depth below—

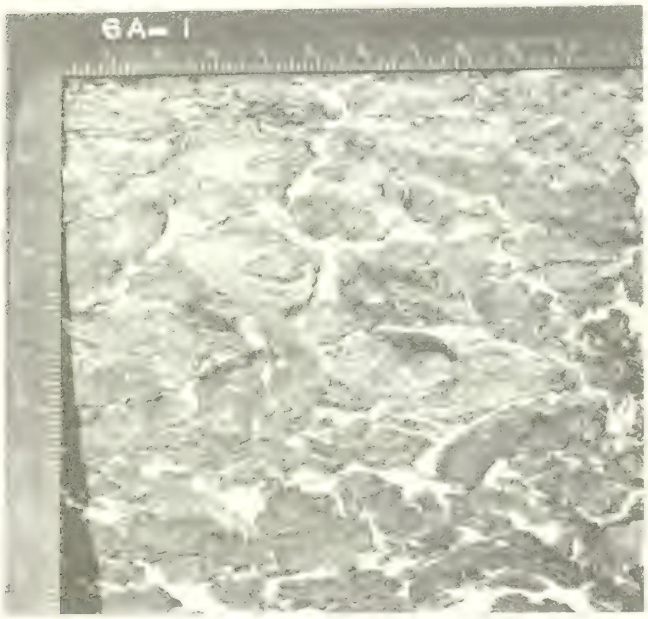
Log surface	First sheet of veneer
6.6 inches	4.5 inches

Depth below—

Log surface	First sheet of veneer
7.3 inches	5.2 inches

Total veneer thickness--5.2 inches

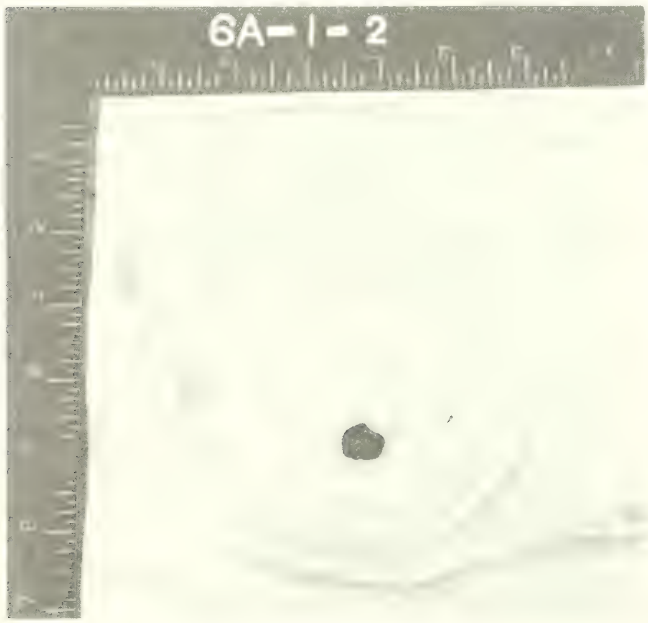
Figure 6.--Medium bark distortions and associated internal defects. (Both are medium bark distortions—data on lower one).



Defect size ..... 1 1/2 x 3 inches
Log diameter ..... 20.2 inches
Log diameter at defect ..... 20.4 inches
Flitch thickness at defect ..... 9.4 inches
Slab + round-up thickness at defect ... 1.3 inches
Log position ..... butt log

Depth below--

Log surface	First sheet of veneer
3.8 inches	2.5 inches

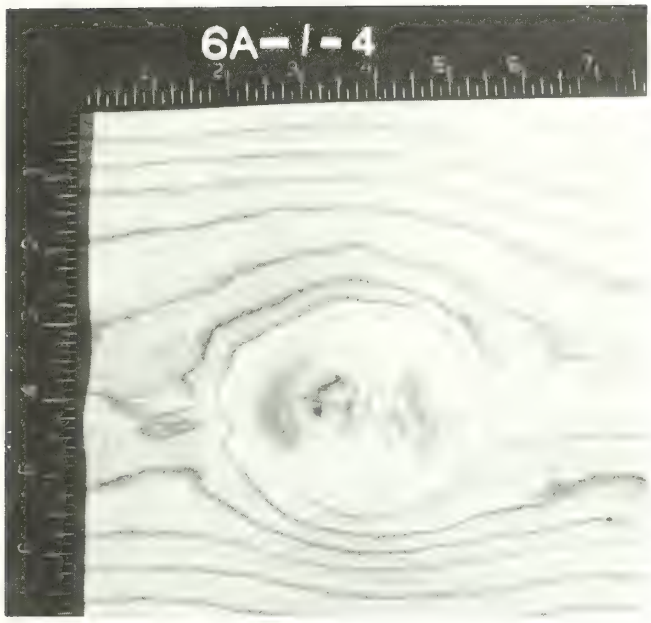


Depth below--

Log surface	First sheet of veneer
4.3 inches	3.0 inches

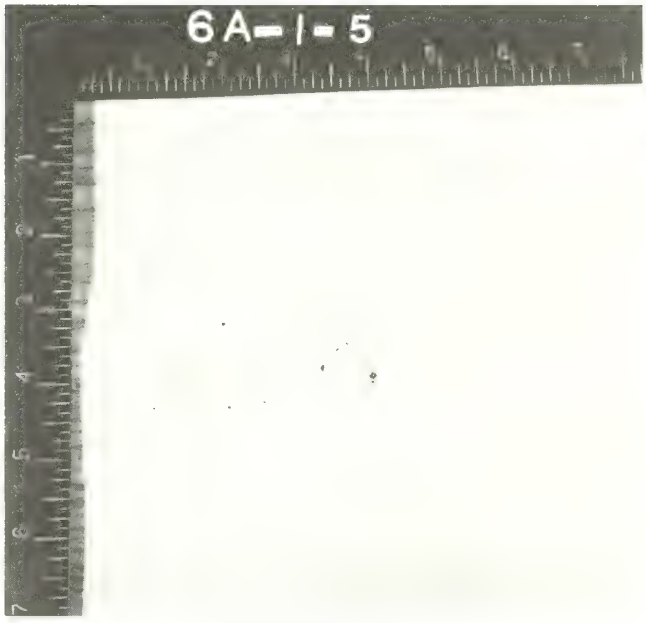
Depth below--

Log surface	First sheet of veneer
4.8 inches	3.5 inches



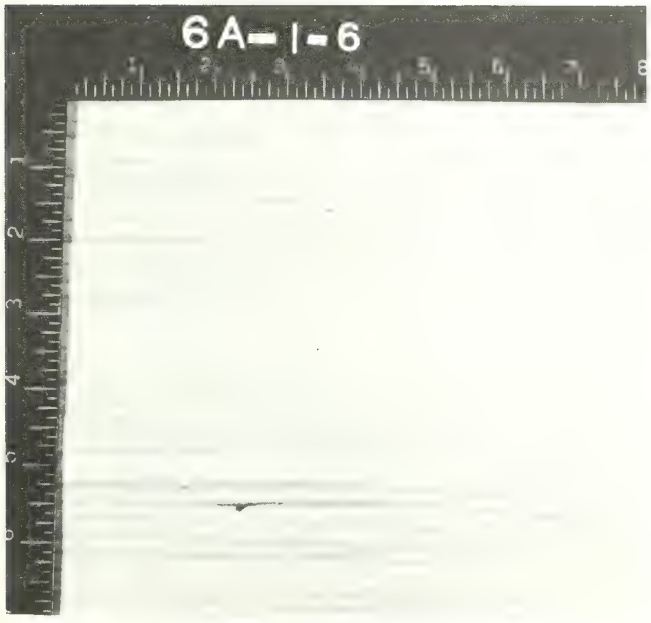
Depth below—

Log surface	First sheet of veneer
5.8 inches	4.5 inches



Depth below—

Log surface	First sheet of veneer
6.3 inches	5.0 inches



Depth below—

Log surface	First sheet of veneer
6.8 inches	5.5 inches

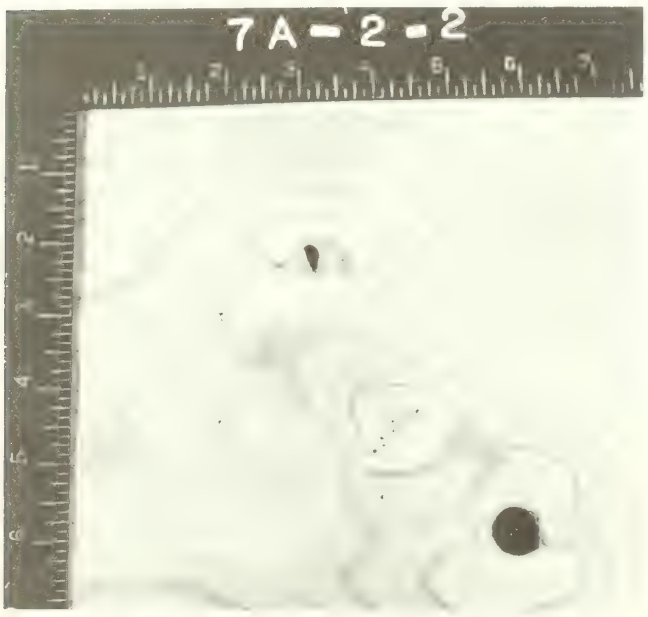
Total veneer thickness—7.0 inches

Figure 7.--Heavy bark distortions and associated internal defects. (Both are heavy bark distortions--data on lower one.)

Defect size ..... 1 1/2 x 2 inches
Log diameter ..... 20.6 inches
Log diameter at defect ..... 21.1 inches
Flitch thickness at defect ..... 10.5 inches
Slab + round-up thickness at defect ... 0.5 inches
Log position ..... butt log

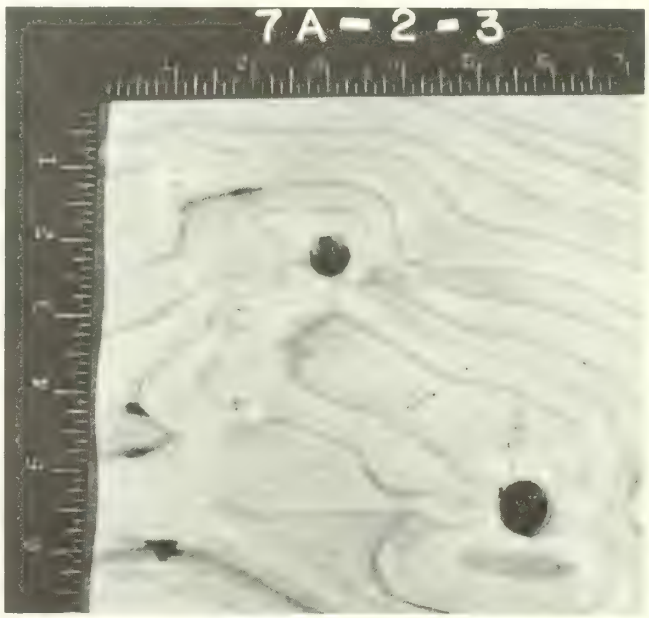
Depth below--

Log surface	First sheet of veneer
0.5 inches	0.0 inches



Depth below--

Log surface	First sheet of veneer
1.5 inches	1.0 inches

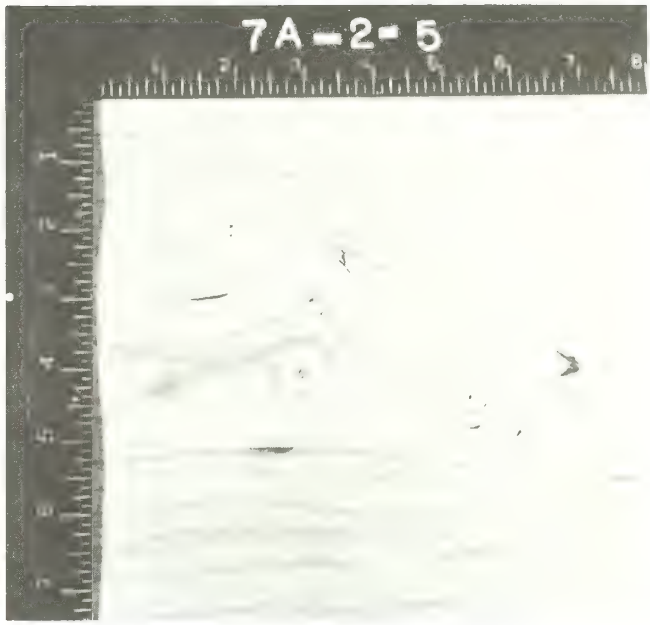


Depth below--

Log surface	First sheet of veneer
2.5 inches	2.0 inches

Depth below--

Log surface	First sheet of veneer
3.2 inches	2.7 inches



Depth below--

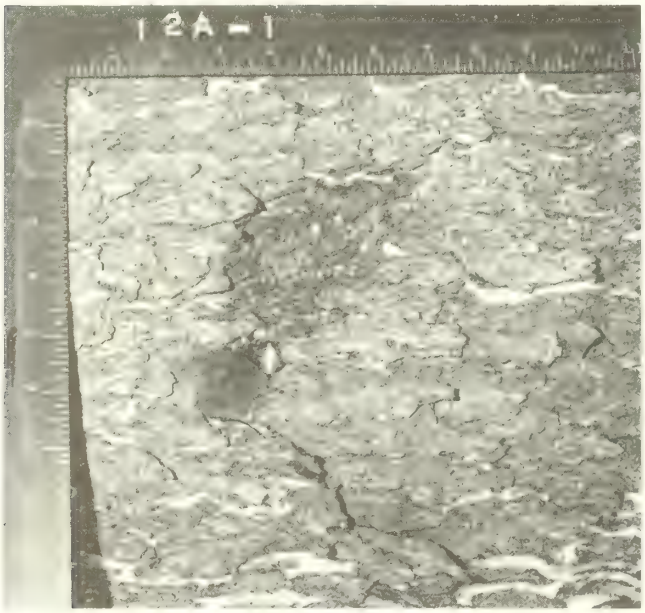
Log surface	First sheet of veneer
4.5 inches	4.0 inches

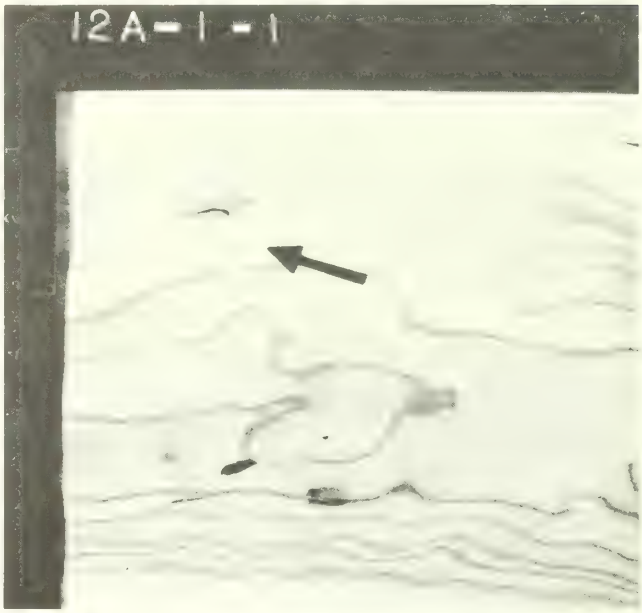
Total veneer thickness--8.2 inches

Wounds

Wounds fall into two categories: sound and unsound. Sound wounds may or may not be degraders depending on their age and depth. If a wound is recent and will be slabbed off during sawing, or deep and likely to be contained in the heart center of the log, then it results in very little degrade. Figure 8 shows a sound wound that did not slab off, but would not be a degrader based on USDA Forest Service grades for factory lumber logs (Rast et al. 1973) since its maximum depth in the logs is only 2.5 inches (15 percent of the log diameter is 2.7). But for veneer logs, this defect is a degrader since it affects the first 40 sheets of veneer. The surrounding bark plates show a distinct break from the callus tissue over the wound, but some breaks showing across the wound callus itself are characteristic of this type of wound.

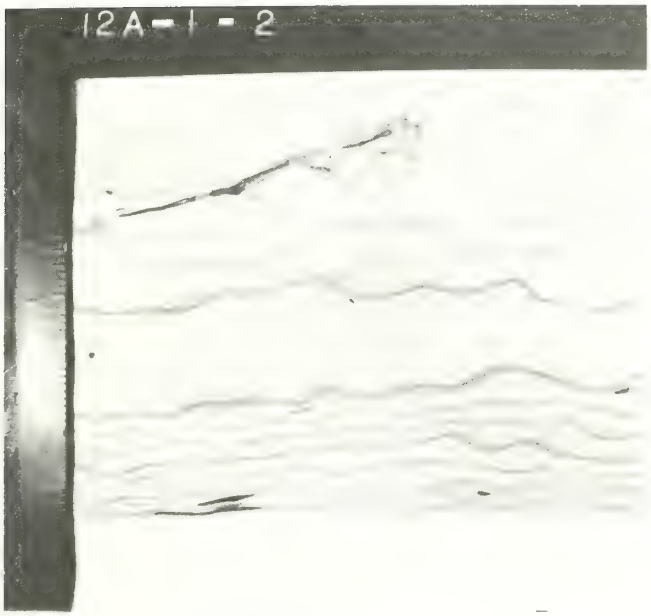
Figure 8.--Overgrown sound wound and associated internal defects.





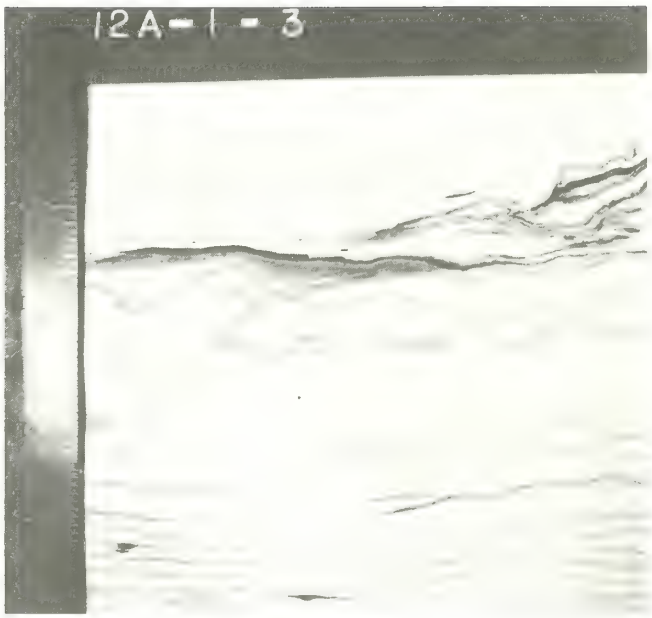
Defect size	3 1/2 x 3 inches
Log diameter	17.3 inches
Log diameter at defect	17.7 inches
Flitch thickness at defect	8.5 inches
Slab + round-up thickness at defect	1.3 inches
Log position	butt log

Depth below--	
Log surface	First sheet of veneer
1.3 inches	0.0 inches



Depth below—

Log surface	First sheet of veneer
1.5 inches	0.2 inches

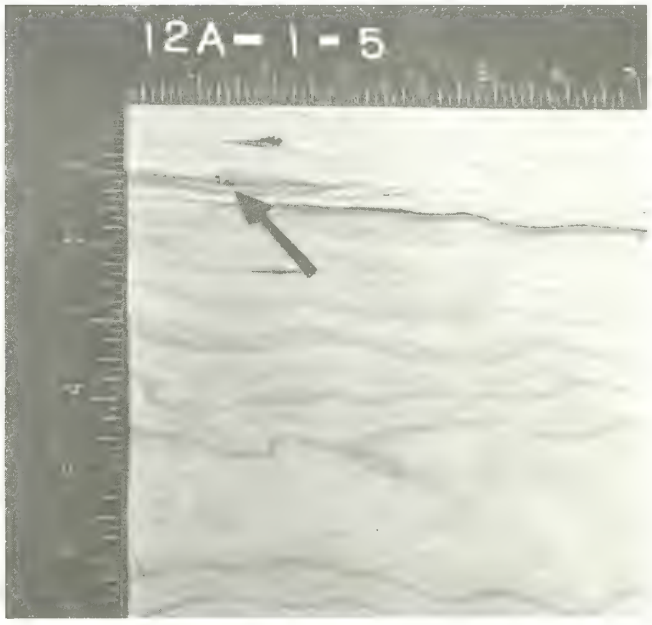


Depth below—

Log surface	First sheet of veneer
1.8 inches	0.5 inches

Depth below—

Log surface	First sheet of veneer
2.2 inches	0.9 inches



Depth below—

Log surface	First sheet of veneer
2.5 inches	1.2 inches

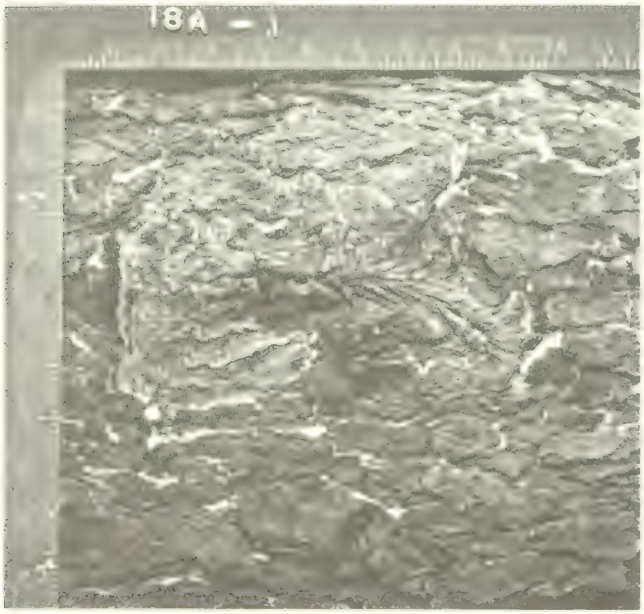
Total veneer thickness—5.4 inches

Wounds that develop callus tissue above the normal curvature of the log surface (height) normally have rot associated with them. The size (8 x 4 inches) and the height (1 inch) of the unsound wound shown in Figure 9 are good indicators of the major degrade caused by this type of defect. In the last defect photos, you can see that this wound occurred over an overgrown knot.

Seams

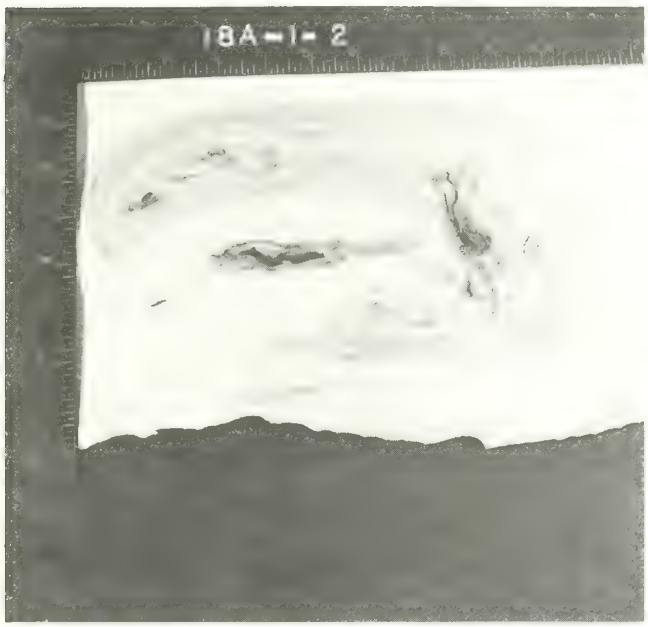
Overgrown seams, one of the exterior indicators of radial shakes, are serious degraders in logs and trees. A common misconception is that seams are caused by frost, but most often they are initiated by wounds or limb stubs (Butin 1981; Shigo 1969). However, frost is one of the major factors in maintaining the stress that causes the seams to persist for many years. Seams with a line of callus and a depressed area (Fig. 10) normally have encased bark that is evidenced as a hole in sliced veneer. This type of defect is serious in logs used to produce lumber or veneer.

Figure 9.—Overgrown unsound wound and associated internal defects.



Defect size	8 x 4 x 1 inches
Log diameter	15.1 inches
Log diameter at defect	15.4 inches
Flitch thickness at defect	6.8 inches
Slab + round-up thickness at defect	1.0 inches
Log position	butt log

Depth below—	
Log surface	First sheet of veneer
1.0 inches	0.0 inches

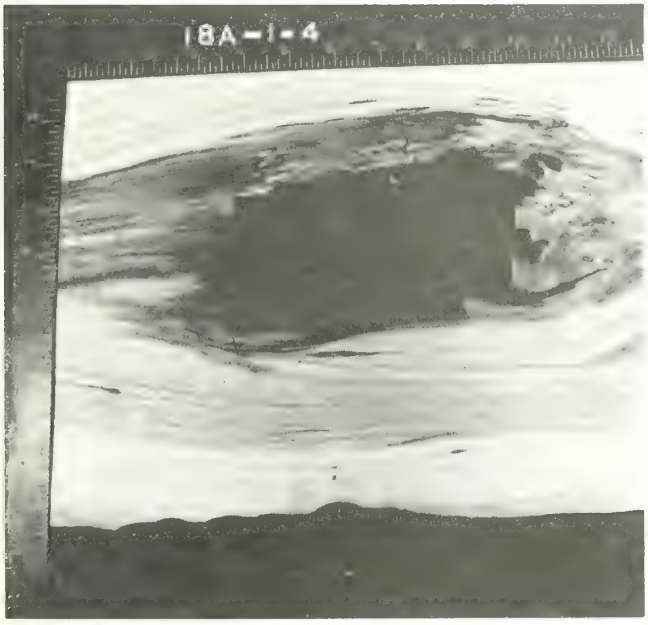


Depth below—

Log surface	First sheet of veneer
1.2 inches	0.2 inches

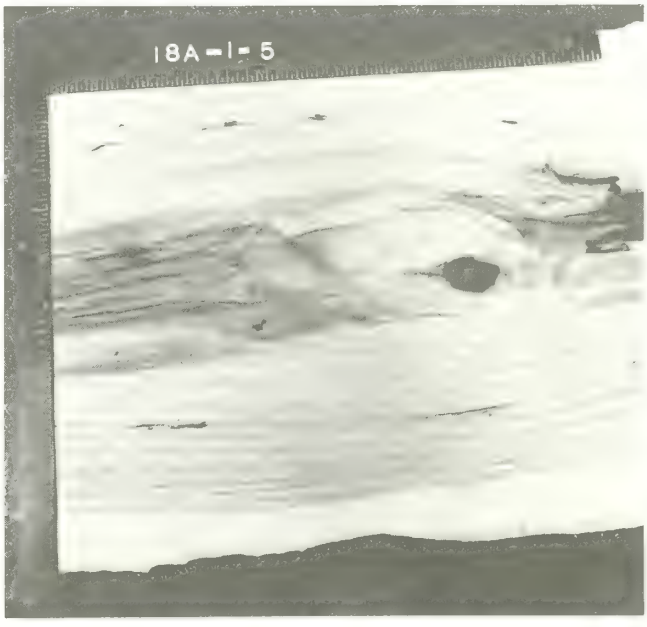
Depth below—

Log surface	First sheet of veneer
1.5 inches	0.5 inches



Depth below—

Log surface	First sheet of veneer
2.0 inches	1.0 inches

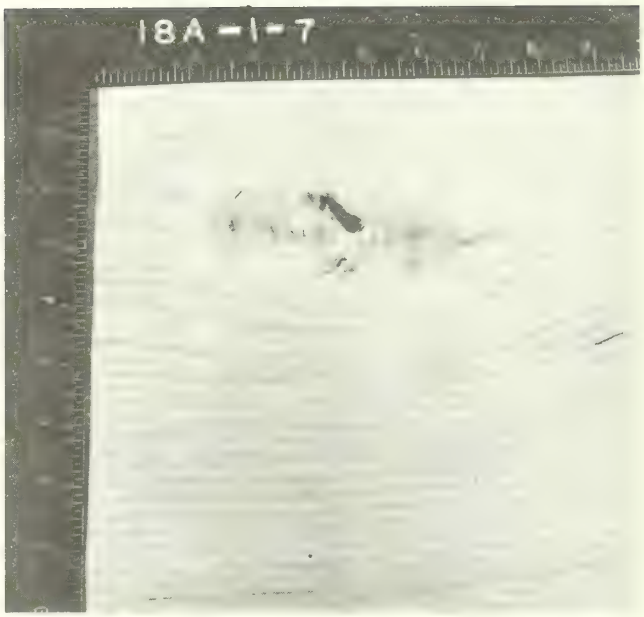


Depth below—

Log surface	First sheet of veneer
2.5 inches	1.5 inches

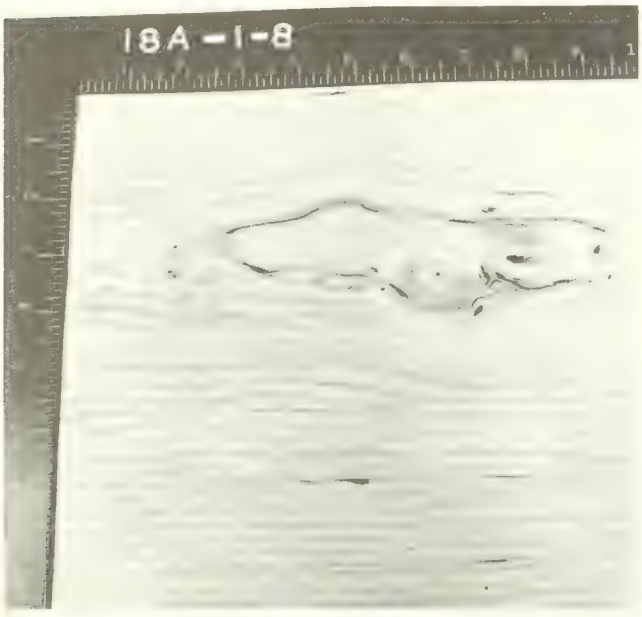
Depth below—

Log surface	First sheet of veneer
3.0 inches	2.0 inches



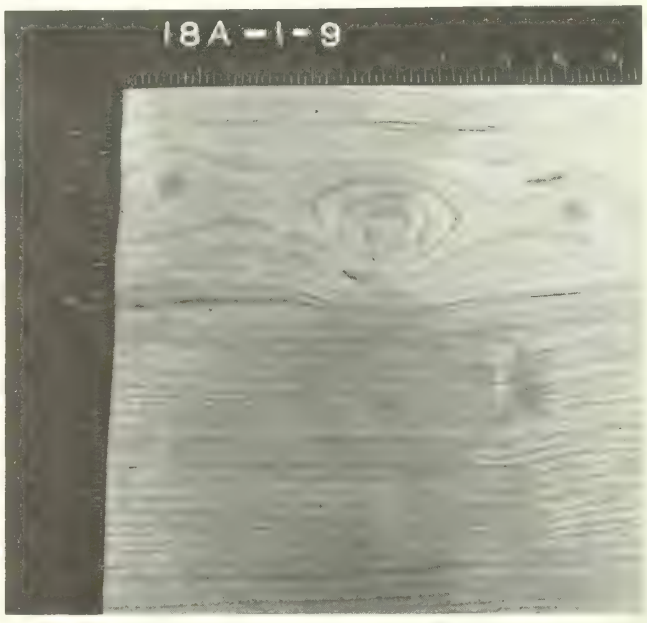
Depth below—

Log surface	First sheet of veneer
4.0 inches	3.0 inches



Depth below—

Log surface	First sheet of veneer
4.5 inches	3.5 inches

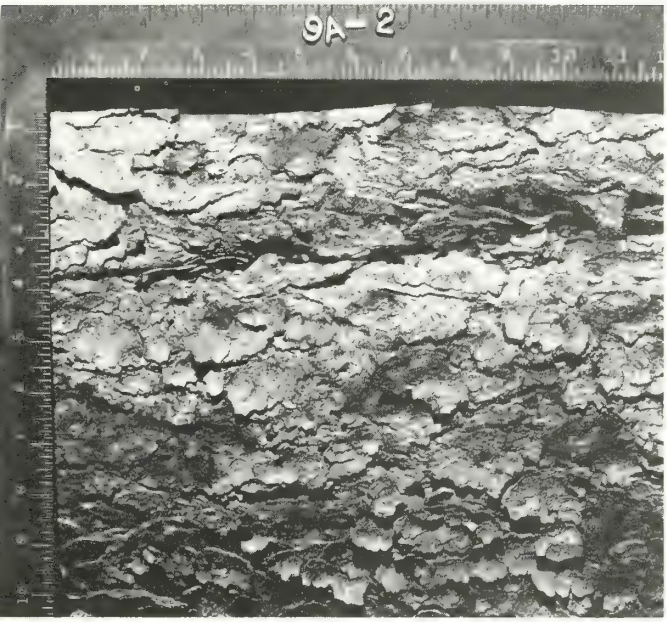


Depth below—

Log surface	First sheet of veneer
5.0 inches	4.0 inches

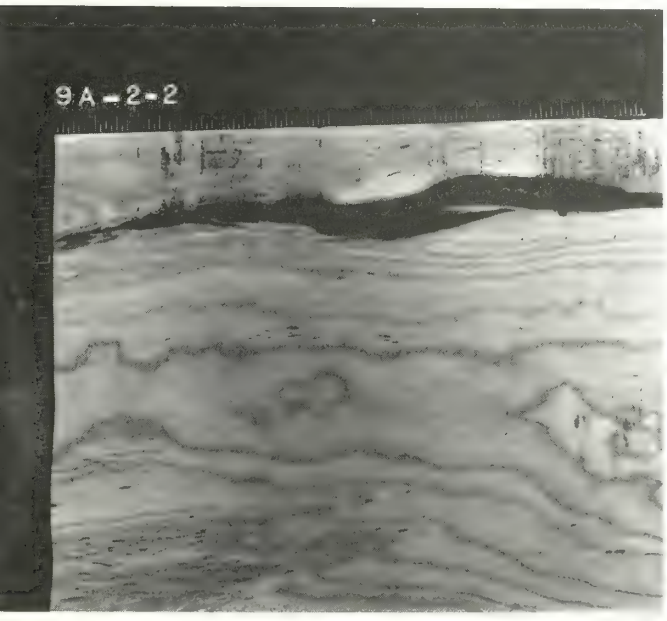
Total veneer thickness—4.9 inches

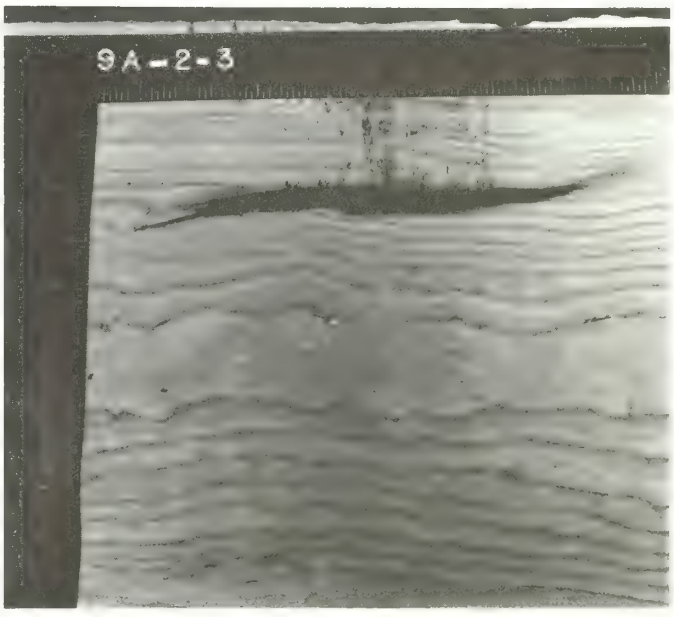
Figure 10.—Overgrown seam and associated internal defects.



Defect size ..... 14 x 2 inches
Log diameter ..... 17.2 inches
Log diameter at defect ..... 17.3 inches
Flitch thickness at defect ..... 7.3 inches
Slab + round-up thickness at defect ... 2.8 inches
Log position ..... butt log

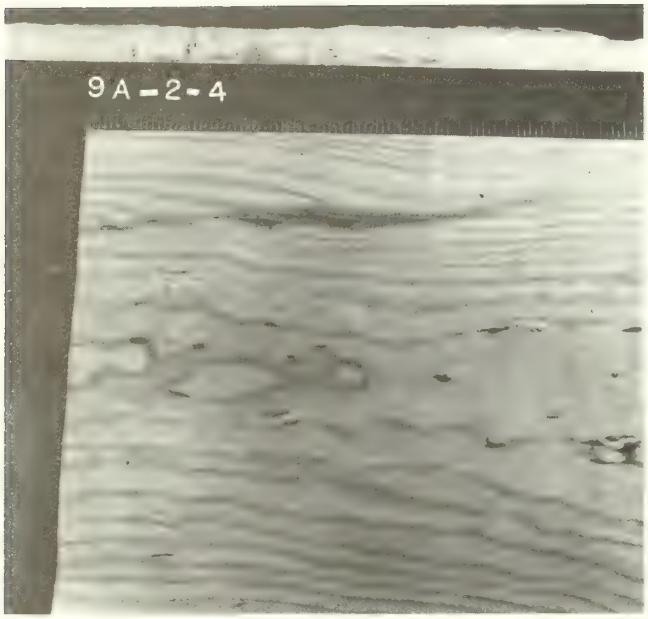
Depth below—	
Log surface	First sheet of veneer
2.8 inches	0.0 inches





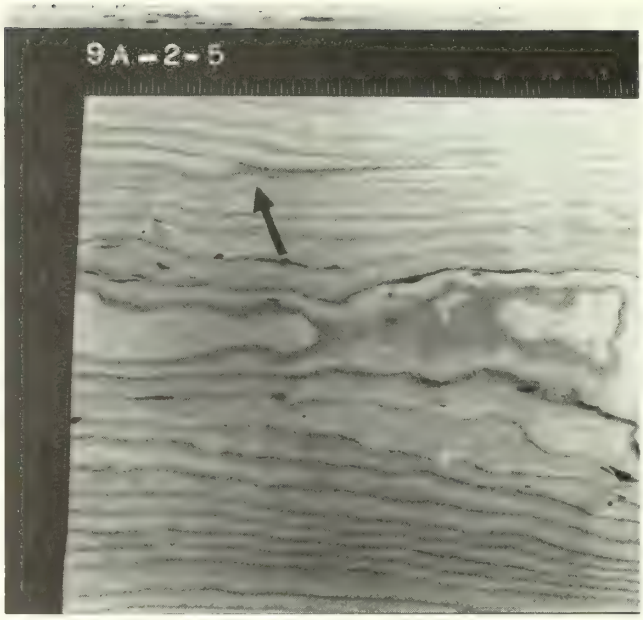
Depth below—	
Log surface	First sheet of veneer
3.8 inches	1.0 inches

Depth below—	
Log surface	First sheet of veneer
4.0 inches	1.2 inches



Depth below—

Log surface	First sheet of veneer
4.1 inches	1.3 inches



Depth below--

Log surface	First sheet of veneer
4.2 inches	1.4 inches

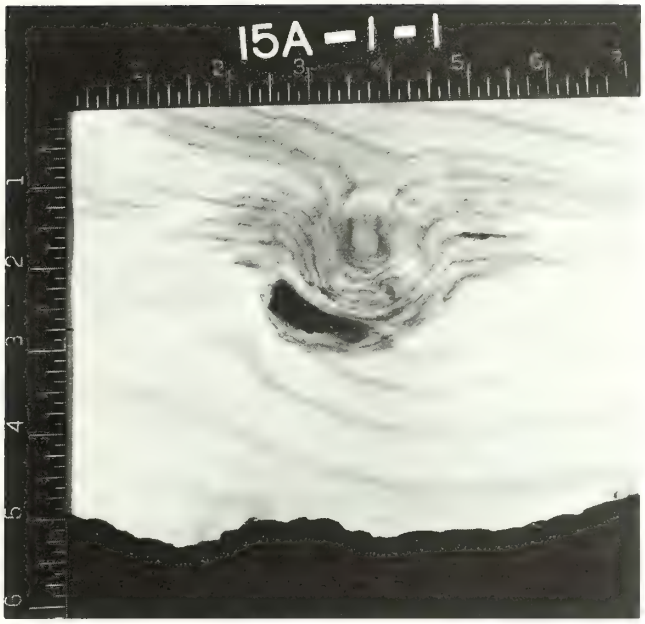
Total veneer thickness—3.7 inches

Figure 11.—Burl and associated internal defects.

Burls

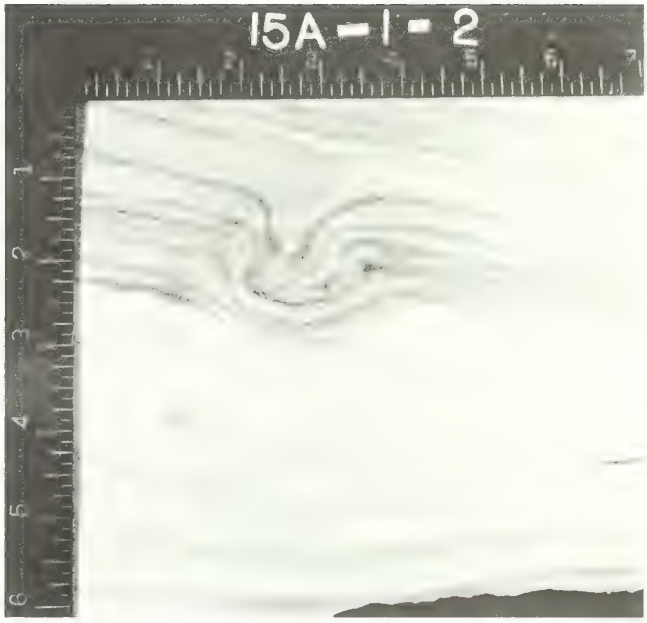
Burls are the surface indicators of distorted grain, and often they contain ingrown bark, rot, and epicormic knots. Figure 11 shows a typical burl on black cherry with a small amount of ingrown bark. Since this burl occurred less than one foot above the stump, more than 2 inches was slabbed off due to butt swell, yet the bark and distorted grain are still evident.

Defect size ..... 3 x 3 x 1 1/2 inches
Log diameter ..... 18.2 inches
Log diameter at defect ..... 19.2 inches
Flitch thickness at defect ..... 7.8 inches
Slab + round-up thickness at defect ... 3.1 inches
Log position ..... butt log



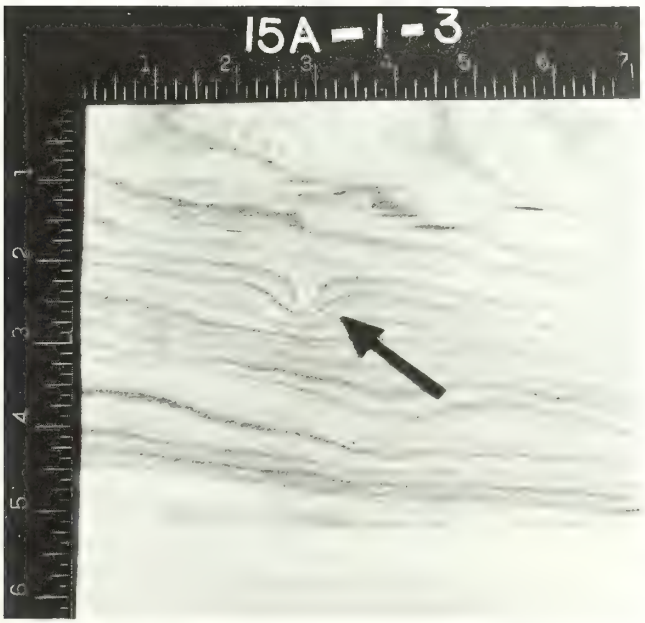
Depth below--

Log surface	First sheet of veneer
3.1 inches	0.0 inches



Depth below--

Log surface	First sheet of veneer
3.6 inches	0.5 inches



Depth below--

Log surface	First sheet of veneer
4.1 inches	1.0 inches

Depth below--

Log surface	First sheet of veneer
4.6 inches	1.5 inches

Total veneer thickness--4.8 inches

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Acknowledgments

The authors wish to thank the Weyerhaeuser Co., Jefferson, Pa., and the Hammermill Paper Co., Coudersport, Pa., for their help and cooperation during this study.

Rast, Everette D.; Beaton, John A. **Photographic guide to selected external defect indicators and associated internal defects in black cherry.** Res. Pap. NE-560. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1985. 22 p.

To properly classify or grade logs or trees, one must be able to correctly identify defect indicators and assess the effect of the underlying defect on possible end products. This guide aids the individual in identifying the surface defect indicator and also shows the progressive stages of the defect throughout its development for black cherry. It illustrates and describes seven types of external defect indicators and associated defects that are particularly difficult to evaluate.

ODC 852.1/.12/.13/.17/.19—(084.121)

Keywords: Defect identification; photo guide; black cherry; quality assessment.

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1985

OAKSIM:
An Individual-Tree Growth and Yield Simulator for Managed, Even-Aged, Upland Oak Stands

Donald E. Hilt

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Manuscript received for publication 21 September 1984.

Abstract

OAKSIM is an individual-tree growth and yield simulator for managed, even-aged, upland oak stands. Growth and yield projections for various thinning alternatives can be made with OAKSIM for up to 50 years. Simulator components include an individual-tree diameter growth model, a mortality model, height prediction equations, bark ratio equations, a taper-based volume system, and a mathematical thinning rule based on actual data. The range of age, site, and stand conditions to which OAKSIM can be applied is discussed, and a numerical example is used to demonstrate computer output generated by the simulator.

Preface

This version of OAKSIM gives users a functional individual-tree growth and yield simulator for managed, even-aged, upland oak stands. A user's guide is in preparation. Improvements to OAKSIM will continue. A comprehensive statistical validation of growth and yield projections will be made when an improved mortality model and an ingrowth model are completed in the near future. A method of projecting individual-tree quality changes in relation to residual stocking after intermediate thinnings will also be incorporated into OAKSIM. Information on tree quality is essential input to an economics subroutine that will be added to determine optimum management alternatives in the upland oak timber type.

Users are encouraged to submit useful changes, extensions, or identified errors to the author for inclusion in the next version of OAKSIM. OAKSIM can become a valuable tool for forest managers only through close cooperation and coordination between researchers and users.

NOTE:

The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program. For cost information write Donald E. Hilt, Northeastern Forest Experiment Station, USDA Forest Service, 359 Main Road, Delaware, OH 43015.

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Introduction

Forest land managers need reliable growth and yield information to manage efficiently the nearly 109 million acres of upland oak timber type in the United States. This paper introduces the initial version of OAKSIM, an individual-tree growth and yield simulator for managed, even-aged, upland oak stands. OAKSIM is designed specifically to help land managers evaluate management alternatives. Although many cultural treatments must be considered for the management of upland oak stands, OAKSIM addresses that silvicultural treatment which has the most potential for influencing tree and stand growth and yield—intermediate thinning. The timing, intensity, and frequency of intermediate thinnings for a wide range of age, site, and stand conditions can be studied in detail with OAKSIM.

Growth and yield projections for up to 50 years after various thinning alternatives can be made with OAKSIM. Existing data bases do not support longer projections. Since OAKSIM is an individual-tree simulator, it provides valuable information on the species and size class of trees in the projected stand. This information is critical for determining the value of trees in the projected stand. Tree values are an essential ingredient for evaluating the economic aspects of thinning, especially in hardwood stands.

OAKSIM is written in FORTRAN and is flexible enough to accommodate a variety of user demands. Input and output program commands make OAKSIM easy to use while preserving the detail that is characteristic of individual-tree simulators. This paper deals primarily with the development and structure of the simulator; a forthcoming user's guide will provide easily understood operating instructions.

OAKSIM can be used to make growth and yield projections for a single stand or group of stands of particular interest, but a more logical approach may be to develop management guidelines by running the simulator for broader categories of age, site, and stand conditions. Management guidelines developed in this manner could be very useful, especially to forest land managers who do not have access to high-speed computers.

Data

Data used to develop the individual-tree diameter growth and mortality models were collected on 77 permanent growth and yield plots in southern Ohio and southeastern Kentucky. Species composition ranged from nearly pure white oak on some Kentucky plots to a mixture of black and scarlet oaks on some Ohio plots.[1] Hickory constituted a minor component of the overstory on some plots. Understory species consisted primarily of dogwood, red maple, yellow-poplar, sourwood, and serviceberry. The even-aged plots ranged from 29 to 93 years in age, and from 60 to 77 in site index according to Schnur's (1937) site index curves. Percent stocking after initial thinnings in 1962 ranged from 16 to 94 according to Gingrich's (1967) tree-area-ratio equation[2] (Fig. 1). Many plots have received a second or third thinning since 1962. The complete data set consists of remeasurements made periodically for 20 years on 9,455 trees that were larger than 2.5 inches d.b.h. after thinning in 1962.

[1] See Little (1978) for scientific names of all species referred to in this paper.

[2] Percent stocking (PS) contributed by the $\underline{i}$th tree in the stand is calculated as follows:

$$PS_i = -.005066 + .016977 * DBH + .003168 * DBH * DBH.$$

Figure 1.—White oak plot in Kentucky, age 33. Stocking was reduced to 37 percent.

The method used to thin the growth and yield plots is best described as "free thinning"--the marker was free to remove trees from all crown classes. The objective was to leave the specified stocking distributed on the best trees as evenly spaced as possible throughout the plot. In general, the larger cull and defective trees were cut first, then the competing trees of poor form and quality, then the intermediate and suppressed trees of lower quality and value. Finally, if necessary, lower value species and even some high-quality desirable species were removed from the main canopy to achieve a uniform spatial distribution. This is the most realistic, practical thinning method that can be applied at the present time by professional foresters in even-aged upland oak stands.

Developing all growth and yield components from one data base is most desirable. Unfortunately, this is seldom possible. A total of 2306 felled-tree and 2313 standing-tree heights were measured on unmanaged even-aged plots in six midwestern states to develop the height prediction equations. Bark-ratio equations were developed from data collected over the entire upland oak range. A total of 1619 trees, representing 10 species groups were sampled. The taper-based volume system was developed from measurements on 418 felled upland oak trees in five midwestern states. Since the height, bark, and volume equations were based on data collected from unmanaged stands, the effects of residual stocking on these components could not be assessed. This is not considered detrimental to OAKSIM's performance, however, because individual-tree diameter growth and mortality are by far the most important components affecting growth and yield projections in managed stands.

Program Structure

A generalized flow chart of the programming logic used in OAKSIM is shown in Figure 2. The control information specifies: (1) type of input data, (2) timing, intensity, and frequency of thinning, (3) tree volume calculations, and (4) type of output. If a stand table is provided in lieu of a tree list, OAKSIM generates a tree list as described later. A summary of initial stand conditions by species and size classes is then computed and printed (Table 1). The stand may be thinned initially or at any 5-year interval to a specified stocking level. A maximum of ten 5-year growth projections may be made. The 5-year intervals provide adequate resolution of growth and yield projections over time for most users. Linear interpolation may be used for estimates between the 5-year intervals.

Diameter growth of each residual tree is predicted for each 5-year period. The probability of mortality for each tree is then determined from this growth, the initial size of the tree, and the species of the tree. If the tree is classified as dead on the basis of this probability and a draw from a random number generator, it is removed from the list. If the net stand basal area growth is not within stand-level growth limitations, a modifier (described later) is applied to the diameter growth calculations and the 5-year growth cycle is repeated.

Inside-and outside-bark volumes to specified top diameters are calculated for individual trees from a predicted total tree height, the appropriate bark ratio equation, and a taper-based volume system. Stand and stock tables by species and size classes are printed after each 5-year interval for the initial stand, thinned trees, residual stand, mortality trees, and projected stand (Table 1). A stand-level summary is printed for each stand after all 5-year projections have been completed (Table 2). This summary is useful for comparing overall thinning strategies.

Program Applications

OAKSIM can be applied to a wide range of stand, age, and site conditions. Like all simulators, however, OAKSIM has limitations, imposed primarily by the data bases used to construct the growth and yield models. Users must be cautious not to exceed these limitations because erroneous projections can occur. OAKSIM applications are limited to the following conditions:

- Even-aged upland oak stands only
- Oak component at least 75 percent of stand basal area
- Stand age 30 to 120 years
- Black oak site index 50 to 85
- Percent stocking 20 to 120 percent
- Tree d.b.h. 2.6 inches and larger
- Maximum 50-year projection

OAKSIM should be applied only to those stands composed primarily of oak species found on upland sites: white, black, scarlet, and chestnut. The simulator is not intended to be used on stands where northern red oak is the major oak component. It can, however, be used on stands where northern red oak is less than 15 percent of the stand basal area.

Stand structure should not differ radically from even-aged structures normally found on upland oak sites. Initial starting ages may range from 30 to 100 years. If the simulator is started at age 100, then projections should only be made for 20 years to the maximum 120 years. The simulator should not be started over. For example, if projections are made from ages 30 to 80, resulting output should not be used as input for a projection from ages 80 to 120. The program will terminate and error messages will be printed if a tree d.b.h. is less than 2.6 inches, or if stand age or site indexes fall outside their respective ranges of application. The user is responsible for meeting the other conditions.

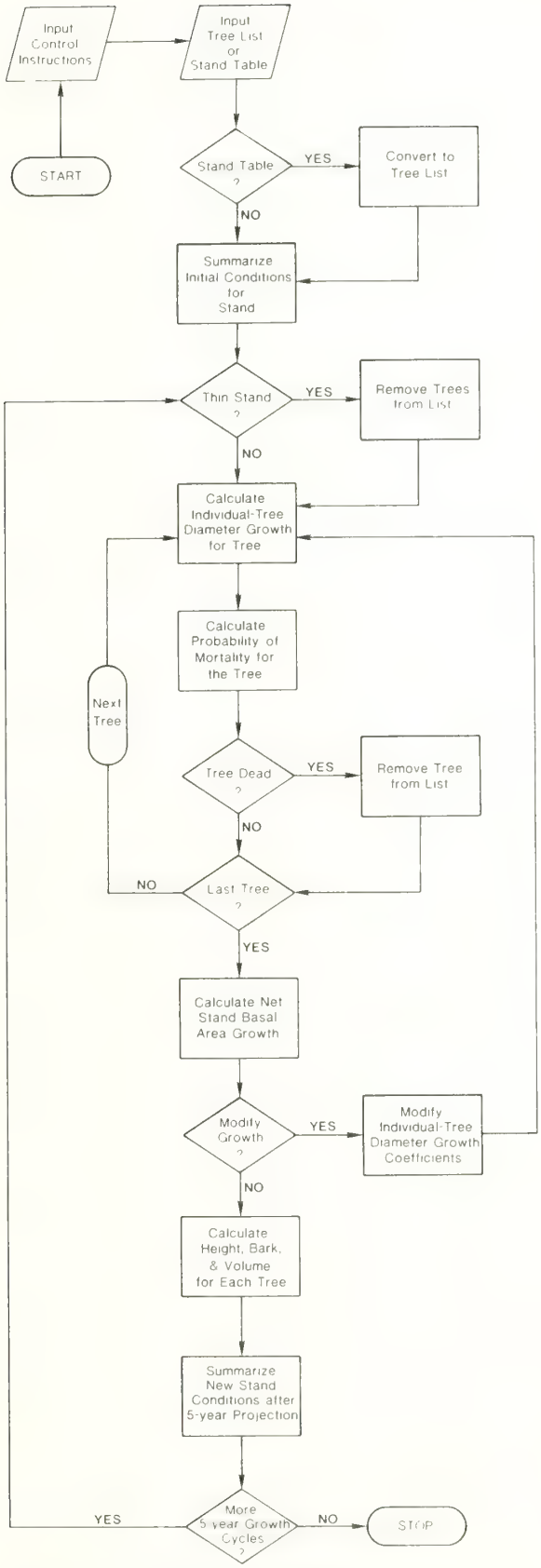

Figure 2.--Generalized flowchart of OAKSIM's operation.

Program Input and Output

OAKSIM is designed to operate from a tree list containing the species and d.b.h. of each tree in the stand, but users may not always have access to a complete list of trees in a stand, except perhaps in research situations. A stand table input option, therefore, is included in OAKSIM to make the simulator more compatible with practical applications. Both the tree list and stand table options must be on a per-acre basis. The number of trees in each size and species (or species group) class must be specified with the stand table option. Size classes may be either 1- or 2-inch d.b.h. classes. A random number generator is called on to distribute the d.b.h.'s of trees in each species and d.b.h. class uniformly across the d.b.h. class. For example, if there are 25 white oak trees in the 6-inch d.b.h. class (a 1-inch class), the generated tree list will include 25 white oak trees uniformly distributed from 5.55 to 6.54 inches. Initial growth projections are then based on this generated tree list. This approach provides a close approximation to the actual distribution of trees across d.b.h. classes. The age and site index (for black oak) must also be entered for each stand.

OAKSIM's flexibility allows users to look at output for virtually any combination of species groups and product size classes. A maximum of five species groups may be specified by the user. Species identification codes in the tree-list or stand-table input will be assembled into groups according to user instructions. Product size classes may also be user-specified into three groups: sapling, pole, and sawtimber. Default values are 4.55 inches for poles and 11.55 inches for sawtimber.

(Text continued on page 11)

TABLE I

DATA TYPE AND STAND INFORMATION.

TYPE OF INPUT DATA: STAND TABLE
NUMBER OF STANDS: 1

STAND NUMBER	AGE	SITE INDEX
1	34.0	66.0

1

VOLUMES TO BE CALCULATED.

	TOP DIAMETERS	
CUBIC VOLUME	4.0	0.0
BOARD FOOT VOLUME	8.0	6.0

2

MINIMUM LENGTH FOR CUBIC VOLUMES IS 4.0 FEET, AND 8.0 FEET FOR BD FT VOLUMES.
PRODUCT SIZE CLASSES ARE 4.55 INCHES FOR POLES, AND 8.55 INCHES FOR SAWLOGS.

HEIGHT AND BARK DATA.

3

SPECIES GROUP	HTGRP	RBAR	B0	B1
1	WO	0.910	0.881	0.056
2	BO	0.900	0.832	0.103
3	WO	0.930	0.919	0.045
4	WO	0.900	0.000	0.000

SPECIES CODES.

4

SPECIES GROUP	SPECIES CODES
1	1
2	2
3	3
4	ALL OTHER CODES ARE IN THIS GROUP.

PROJECTIONS.

5

NUMBER OF 5-YEAR PROJECTIONS: 10
1ST & LAST STAND-STOCK TABLES ALWAYS PRINTED.
ALL STAND TABLES PRINTED: YES
ALL STOCK TABLES PRINTED: NO

THINNING OPTIONS.

6

NUMBER OF THINNINGS: 1
THINNING METHOD: FREE THINNING
THINNING INTENSITIES BY SPECIES GROUPS: 0 0 0 0

AGE THINNED	PERCENT STOCKING
34	40.0

TABLE I (continued) 7

SUMMARY STAND STATISTICS: INITIAL CONDITIONS FOR STAND AT AGE 34.

SPECIES :	1	2	3	4	5	TOTALS
N TREES:						
SAP	512.0	44.0	12.0	16.0		584.0
POLE	110.0	48.0	2.0	6.0		166.0
SAW	0.0	0.0	0.0	0.0		0.0
TOTAL	622.0	92.0	14.0	22.0		750.0
BA:						
SAP	34.1	3.0	0.8	1.2		39.1
POLE	17.6	8.7	0.3	0.9		27.5
SAW	0.0	0.0	0.0	0.0		0.0
TOTAL	51.7	11.6	1.2	2.1		66.6
PS:						
SAP	47.2	4.1	1.1	1.6		54.0
POLE	19.7	9.4	0.3	1.0		30.5
SAW	0.0	0.0	0.0	0.0		0.0
TOTAL	66.9	13.5	1.5	2.6		84.5
AVG DBH:						
SAP	3.4	3.5	3.5	3.6		3.5
POLE	5.4	5.7	5.3	5.3		5.5
SAW	0.0	0.0	0.0	0.0		0.0
CVOB 4.0:						
SAP	0.0	0.0	0.0	0.0		0.0
POLE	225.7	126.0	3.0	12.7		367.4
SAW	0.0	0.0	0.0	0.0		0.0
TOTAL	225.7	126.0	3.0	12.7		367.4
CVIB 4.0:						
SAP	0.0	0.0	0.0	0.0		0.0
POLE	196.7	108.2	2.8	10.3		317.9
SAW	0.0	0.0	0.0	0.0		0.0
TOTAL	196.7	108.2	2.8	10.3		317.9
CVOB 0.0:						
SAP	624.2	59.2	15.2	23.3		721.9
POLE	388.5	199.2	5.9	22.0		615.5
SAW	0.0	0.0	0.0	0.0		0.0
TOTAL	1012.7	258.3	21.1	45.3		1337.4
CVIB 0.0:						
SAP	537.1	49.7	13.9	18.9		619.6
POLE	333.8	167.1	5.4	17.8		524.0
SAW	0.0	0.0	0.0	0.0		0.0
TOTAL	870.9	216.8	19.3	36.7		1143.7
BFVOL 8.0:						
SAW	0.0	0.0	0.0	0.0		0.0
BFVOL 6.0:						
SAW	0.0	0.0	0.0	0.0		0.0

8

TABLE I (continued)

STAND TABLE: INITIAL CONDITIONS FOR STAND AT AGE 34.

DBH CLASS	SPECIES GROUPS 1	2	3	4	5	TOTALS
3	298.0	22.0	6.0	6.0	9	332.0
4	214.0	22.0	6.0	10.0		252.0
5	86.0	24.0	2.0	4.0		116.0
6	14.0	20.0	0.0	2.0		36.0
7	10.0	2.0	0.0	0.0		12.0
8	0.0	2.0	0.0	0.0		2.0
TOTALS	622.0	92.0	14.0	22.0		750.0

STAND TABLE: TREES REMOVED IN THINNING AT AGE 34.

DBH CLASS	SPECIES GROUPS 1	2	3	4	5	TOTALS
3	239.0	15.0	4.0	4.0	10	262.0
4	100.0	10.0	3.0	5.0		118.0
5	30.0	9.0	1.0	2.0		42.0
6	5.0	7.0	0.0	1.0		13.0
7	3.0	1.0	0.0	0.0		4.0
8	0.0	1.0	0.0	0.0		1.0
9	0.0	0.0	0.0	0.0		0.0
10	0.0	0.0	0.0	0.0		0.0
TOTALS	377.0	43.0	8.0	12.0		440.0

STAND TABLE: RESIDUAL STAND AFTER THINNING AT AGE 34.

DBH CLASS	SPECIES GROUPS 1	2	3	4	5	TOTALS
3	59.0	7.0	2.0	2.0	11	70.0
4	114.0	12.0	3.0	5.0		134.0
5	56.0	15.0	1.0	2.0		74.0
6	9.0	13.0	0.0	1.0		23.0
7	7.0	1.0	0.0	0.0		8.0
8	0.0	1.0	0.0	0.0		1.0
9	0.0	0.0	0.0	0.0		0.0
10	0.0	0.0	0.0	0.0		0.0
TOTALS	245.0	49.0	6.0	10.0		310.0

STAND TABLE: MORTALITY FOR GROWTH PERIOD BEGINNING AT AGE 34.

DBH CLASS	SPECIES GROUPS 1	2	3	4	5	TOTALS
3	3.0	1.0	0.0	0.0	12	4.0
4	1.0	0.0	0.0	0.0		1.0
5	1.0	0.0	0.0	0.0		1.0
6	0.0	0.0	0.0	0.0		0.0
7	0.0	0.0	0.0	0.0		0.0
8	0.0	0.0	0.0	0.0		0.0
9	0.0	0.0	0.0	0.0		0.0
10	0.0	0.0	0.0	0.0		0.0
TOTALS	5.0	1.0	0.0	0.0		6.0

STAND TABLE: INITIAL CONDITIONS FOR STAND AT AGE 39.

DBH CLASS	SPECIES GROUPS 1	2	3	4	5	TOTALS
3	27.0	3.0	1.0	0.0	13	31.0
4	81.0	11.0	3.0	2.0		97.0
5	72.0	7.0	1.0	5.0		85.0
6	44.0	12.0	1.0	2.0		59.0
7	7.0	10.0	0.0	1.0		18.0
8	4.0	4.0	0.0	0.0		8.0
9	5.0	0.0	0.0	0.0		5.0
10	0.0	1.0	0.0	0.0		1.0
TOTALS	240.0	48.0	6.0	10.0		304.0

STAND TABLE: INITIAL CONDITIONS FOR STAND AT AGE 84.

DBH CLASS	SPECIES GROUPS 1	2	3	4	5	TOTALS
5	1.0	0.0	0.0	0.0	14	1.0
6	9.0	1.0	2.0	0.0		12.0
7	20.0	2.0	1.0	0.0		23.0
8	41.0	1.0	0.0	2.0		44.0
9	43.0	6.0	0.0	1.0		50.0
10	22.0	6.0	1.0	1.0		30.0
11	13.0	3.0	0.0	1.0		17.0
12	5.0	5.0	1.0	0.0		11.0
13	2.0	6.0	0.0	0.0		8.0
14	4.0	1.0	0.0	0.0		5.0
15	1.0	0.0	0.0	0.0		1.0
16	3.0	0.0	0.0	0.0		3.0
17	0.0	1.0	0.0	0.0		1.0
TOTALS	164.0	32.0	5.0	5.0		206.0

TABLE I (continued)

SUMMARY STAND STATISTICS: INITIAL CONDITIONS FOR STAND AT AGE 84.

15

SPECIES :	1	2	3	4	5	TOTALS
N TREES:						
SAP	0.0	0.0	0.0	0.0		0.0
POLE	71.0	4.0	3.0	2.0		80.0
SAW	93.0	28.0	2.0	3.0		126.0
TOTAL	164.0	32.0	5.0	5.0		206.0
BA:						
SAP	0.0	0.0	0.0	0.0		0.0
POLE	21.7	1.1	0.7	0.7		24.2
SAW	55.2	19.9	1.3	1.7		78.1
TOTAL	76.9	21.0	2.0	2.4		102.3
PS:						
SAP	0.0	0.0	0.0	0.0		0.0
POLE	21.2	1.1	0.7	0.7		23.7
SAW	47.9	16.8	1.1	1.5		67.2
TOTAL	69.1	17.9	1.8	2.1		90.9
AVG DBH:						
SAP	0.0	0.0	0.0	0.0		0.0
POLE	7.5	7.1	6.4	8.1		7.4
SAW	10.3	11.3	11.0	10.1		10.5
CVOB 4.0:						
SAP	0.0	0.0	0.0	0.0		0.0
POLE	609.1	28.3	15.3	21.7		674.4
SAW	1978.3	676.0	48.4	60.0		2762.7
TOTAL	2587.4	704.3	63.6	81.8		3437.1
CVIB 4.0:						
SAP	0.0	0.0	0.0	0.0		0.0
POLE	525.5	24.0	14.0	17.6		581.1
SAW	1699.6	566.9	44.1	48.6		2359.2
TOTAL	2225.0	590.9	58.2	66.2		2940.3
CVOB 0.0:						
SAP	0.0	0.0	0.0	0.0		0.0
POLE	704.9	34.5	19.5	24.3		783.1
SAW	2071.2	702.8	50.0	63.1		2887.1
TOTAL	2776.0	737.3	69.5	87.4		3670.2
CVIB 0.0:						
SAP	0.0	0.0	0.0	0.0		0.0
POLE	604.3	28.8	17.8	19.7		670.6
SAW	1774.9	587.0	45.6	51.1		2458.6
TOTAL	2379.2	615.8	63.3	70.8		3129.2
BFVOL 8.0:						
SAW	3918.9	1721.8	145.3	88.5		5874.5
BFVOL 6.0:						
SAW	7263.7	2533.1	199.7	198.2		10194.7

TABLE I (continued)

SUMMARY STATISTICS FOR ENTIRE GROWTH PROJECTION:

ATTRIBUTE	STAND AGE 34	39	44	49	54	59	64	69	74	79	84	TOTALS
N TREES:												
INITIAL	750.0	304.0	290.0	281.0	269.0	261.0	250.0	240.0	227.0	216.0	206.0	-----
CUT	440.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		440.0
RESIDUAL	310.0	304.0	290.0	281.0	269.0	261.0	250.0	240.0	227.0	216.0		-----
MORTALITY	6.0	14.0	9.0	12.0	8.0	11.0	10.0	13.0	11.0	10.0		104.0
BA:												
INITIAL	66.6	44.4	55.0	64.3	72.4	79.3	85.2	90.4	94.9	98.8	102.3	-----
CUT	33.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		33.8
RESIDUAL	32.8	44.4	55.0	64.3	72.4	79.3	85.2	90.4	94.9	98.8		-----
MORTALITY	0.4	1.0	1.0	1.8	1.3	2.1	2.5	2.6	3.2	3.4		19.2
NET GROWTH	11.6	10.6	9.3	8.1	6.9	6.0	5.2	4.5	3.9	3.5		69.5
GROSS GROWTH	12.0	11.6	10.3	9.9	8.2	8.0	7.7	7.1	7.1	6.9		88.7
PS:												
INITIAL	84.5	50.2	58.7	66.0	71.9	76.9	80.9	84.3	86.9	89.1	90.9	-----
CUT	44.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		44.5
RESIDUAL	40.0	50.2	58.7	66.0	71.9	76.9	80.9	84.3	86.9	89.1		-----
MORTALITY	0.5	1.3	1.2	2.1	1.4	2.2	2.5	2.8	3.1	3.2		20.4
NET GROWTH	10.2	8.5	7.3	5.9	5.1	4.0	3.3	2.6	2.2	1.9		50.9
GROSS GROWTH	10.7	9.9	8.5	8.0	6.5	6.2	5.9	5.4	5.3	5.1		71.4
QUADRATIC DBH:												
INITIAL	4.0	5.2	5.9	6.5	7.0	7.5	7.9	8.3	8.8	9.2	9.5	-----
CUT	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		3.8
RESIDUAL	4.4	5.2	5.9	6.5	7.0	7.5	7.9	8.3	8.8	9.2		-----
MORTALITY	3.4	3.6	4.4	5.3	5.4	5.9	6.8	6.1	7.3	7.9		56.0
CVOB 4.0:												
INITIAL	367.4	506.2	969.8	1352.0	1699.4	2089.5	2327.8	2655.2	2990.9	3171.4	3437.1	-----
CUT	133.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		133.2
RESIDUAL	234.1	506.2	969.8	1352.0	1699.4	2089.5	2327.8	2655.2	2990.9	3171.4		-----
MORTALITY	1.4	0.0	5.9	28.6	20.9	38.2	62.3	54.0	87.1	100.3		398.7
NET GROWTH	272.1	463.6	382.2	347.4	390.1	238.3	327.4	335.7	180.6	265.6		3202.9
GROSS GROWTH	273.5	463.6	388.1	375.9	411.0	276.5	389.7	389.7	267.7	365.9		3601.6
CVIB 4.0:												
INITIAL	317.9	436.8	835.2	1162.7	1460.5	1792.8	1996.5	2275.8	2561.2	2713.7	2940.3	-----
CUT	115.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		115.2
RESIDUAL	202.8	436.8	835.2	1162.7	1460.5	1792.8	1996.5	2275.8	2561.2	2713.7		-----
MORTALITY	1.2	0.0	5.1	24.0	17.8	33.1	53.0	46.8	75.2	85.8		342.0
NET GROWTH	234.0	398.4	327.5	297.8	332.2	203.7	279.4	285.3	152.5	226.6		2737.5
GROSS GROWTH	235.3	398.4	332.6	321.8	350.1	236.8	332.4	332.1	227.7	312.4		3079.5
CVOB 0.0:												
INITIAL	1337.4	960.4	1409.2	1765.5	2077.6	2443.2	2652.8	2958.2	3266.1	3425.8	3670.2	-----
CUT	652.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		652.2
RESIDUAL	685.3	960.4	1409.2	1765.5	2077.6	2443.2	2652.8	2958.2	3266.1	3425.8		-----
MORTALITY	8.2	18.0	21.2	49.1	34.6	56.1	77.1	75.0	102.6	113.8		555.6
NET GROWTH	275.1	448.8	356.3	312.1	365.5	209.7	305.4	307.8	159.7	244.4		2985.0
GROSS GROWTH	283.3	466.8	377.5	361.2	400.2	265.7	382.5	382.8	262.3	358.3		3540.6

TABLE I (continued)

ATTRIBUTE	STAND AGE 34	39	44	49	54	59	64	69	74	79	84	TOTALS
CVIB 0.0:												
INITIAL	1143.7	819.5	1202.4	1506.3	1773.2	2084.1	2263.0	2523.7	2785.3	2920.3	3129.2	-----
CUT	558.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		558.2
RESIDUAL	585.4	819.5	1202.4	1506.3	1773.2	2084.1	2263.0	2523.7	2785.3	2920.3		-----
MORTALITY	7.0	15.3	18.1	41.2	29.2	48.1	65.1	64.3	88.0	96.8		473.1
NET GROWTH	234.0	382.9	303.9	266.9	310.9	178.9	260.7	261.6	135.1	208.9		2543.8
GROSS GROWTH	241.1	398.3	322.0	308.0	340.1	227.0	325.8	325.9	223.0	305.7		3016.9
BFVOL 8.0:												
INITIAL	0.0	0.0	140.3	385.6	812.3	1367.2	1688.7	2830.8	3908.1	4676.7	5874.5	-----
CUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
RESIDUAL	0.0	0.0	140.3	385.6	812.3	1367.2	1688.7	2830.8	3908.1	4676.7		-----
MORTALITY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.5	90.5		122.0
NET GROWTH	0.0	140.3	245.3	426.7	554.9	321.5	1142.2	1077.2	768.7	1197.7		5874.5
GROSS GROWTH	0.0	140.3	245.3	426.7	554.9	321.5	1142.2	1077.2	800.2	1288.2		5996.5
BFVOL 6.0:												
INITIAL	0.0	0.0	546.6	1080.2	1866.5	3198.8	3982.0	5509.3	7287.8	8692.5	10194.7	-----
CUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
RESIDUAL	0.0	0.0	546.6	1080.2	1866.5	3198.8	3982.0	5509.3	7287.8	8692.5		-----
MORTALITY	0.0	0.0	0.0	36.2	0.0	0.0	40.0	0.0	65.5	154.0		295.7
NET GROWTH	0.0	546.6	533.5	786.3	1332.3	783.2	1527.2	1778.6	1404.7	1502.2		10194.7
GROSS GROWTH	0.0	546.6	533.5	822.5	1332.3	783.2	1567.2	1778.6	1470.1	1656.2		10490.3

TABLE 2 SUMMARY STATISTICS FOR ENTIRE GROWTH PROJECTION:

ATTRIBUTE	STAND AGE 34	39	44	49	54	59	64	69	74	79	84	TOTALS
N TREES:												
INITIAL	750.0	653.0	572.0	508.0	457.0	419.0	384.0	354.0	328.0	301.0	281.0	-----
CUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
RESIDUAL	750.0	653.0	572.0	508.0	457.0	419.0	384.0	354.0	328.0	301.0		-----
MORTALITY	97.0	81.0	64.0	51.0	38.0	35.0	30.0	26.0	27.0	20.0		469.0
BA:												
INITIAL	66.6	75.8	83.2	89.2	94.2	98.4	102.0	105.0	107.8	110.2	112.3	-----
CUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
RESIDUAL	66.6	75.8	83.2	89.2	94.2	98.4	102.0	105.0	107.8	110.2		-----
MORTALITY	5.8	6.7	6.2	5.9	5.8	6.0	5.4	5.4	6.3	5.5		58.9
NET GROWTH	9.2	7.4	6.0	5.0	4.2	3.6	3.1	2.7	2.4	2.2		45.7
GROSS GROWTH	15.0	14.1	12.2	10.8	10.0	9.6	8.5	8.2	8.7	7.6		104.7
PS:												
INITIAL	84.5	90.3	94.1	96.8	98.8	100.5	101.7	102.5	103.2	103.4	103.8	-----
CUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
RESIDUAL	84.5	90.3	94.1	96.8	98.8	100.5	101.7	102.5	103.2	103.4		-----
MORTALITY	8.2	8.7	7.8	7.0	6.5	6.6	5.9	5.7	6.5	5.4		68.3
NET GROWTH	5.7	3.8	2.7	2.0	1.7	1.1	0.9	0.6	0.2	0.4		19.3
GROSS GROWTH	13.9	12.5	10.5	9.1	8.2	7.7	6.7	6.4	6.7	5.8		87.6

TABLE 2 (continued)

ATTRIBUTE	STAND AGE 34	39	44	49	54	59	64	69	74	79	84	TOTALS
QUADRATIC DBH:												
INITIAL	4.0	4.6	5.2	5.7	6.1	6.6	7.0	7.4	7.8	8.2	8.6	-----
CUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
RESIDUAL	4.0	4.6	5.2	5.7	6.1	6.6	7.0	7.4	7.8	8.2		-----
MORTALITY	3.3	3.9	4.2	4.6	5.3	5.6	5.7	6.2	6.6	7.1		52.5
CVOB 4.0:												
INITIAL	367.4	722.7	1094.1	1458.8	1903.1	2144.6	2453.1	2797.0	3040.7	3308.2	3487.3	-----
CUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
RESIDUAL	367.4	722.7	1094.1	1458.8	1903.1	2144.6	2453.1	2797.0	3040.7	3308.2		-----
MORTALITY	7.5	24.4	34.5	47.1	87.3	106.9	88.8	107.9	137.9	135.6		778.0
NET GROWTH	355.4	371.4	364.7	444.3	241.5	308.5	343.9	243.6	267.6	179.1		3120.0
GROSS GROWTH	362.8	395.8	399.2	491.4	328.8	415.4	432.8	351.5	405.5	314.7		3897.9
CVIB 4.0:												
INITIAL	317.9	625.2	945.2	1258.5	1638.3	1845.3	2108.7	2401.3	2609.1	2836.9	2990.0	-----
CUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
RESIDUAL	317.9	625.2	945.2	1258.5	1638.3	1845.3	2108.7	2401.3	2609.1	2836.9		-----
MORTALITY	6.4	21.1	29.8	40.7	75.2	92.0	76.5	92.7	117.7	116.2		668.4
NET GROWTH	307.2	320.0	313.3	379.8	207.0	263.4	292.6	207.9	227.8	153.1		2672.1
GROSS GROWTH	313.7	341.1	343.1	420.5	282.2	355.4	369.1	300.6	345.5	269.3		3340.4
CVOB 0.0:												
INITIAL	1337.4	1674.0	2001.4	2271.7	2617.9	2779.3	3017.3	3294.4	3484.5	3699.2	3838.0	-----
CUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
RESIDUAL	1337.4	1674.0	2001.4	2271.7	2617.9	2779.3	3017.3	3294.4	3484.5	3699.2		-----
MORTALITY	107.6	137.0	137.0	134.9	152.8	166.8	140.9	150.2	181.5	165.7		1474.3
NET GROWTH	336.6	327.3	270.3	346.3	161.4	237.9	277.1	190.1	214.7	138.8		2500.6
GROSS GROWTH	444.2	464.3	407.3	481.2	314.2	404.7	418.0	340.3	396.3	304.4		3974.9
CVIB 0.0:												
INITIAL	1143.7	1431.2	1710.3	1940.8	2234.6	2372.4	2575.6	2811.2	2973.9	3157.2	3276.5	-----
CUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
RESIDUAL	1143.7	1431.2	1710.3	1940.8	2234.6	2372.4	2575.6	2811.2	2973.9	3157.2		-----
MORTALITY	92.1	116.9	117.0	115.5	130.3	141.8	119.9	127.9	153.8	141.0		1256.3
NET GROWTH	287.5	279.1	230.5	293.8	137.8	203.1	235.7	162.7	183.3	119.3		2132.9
GROSS GROWTH	379.6	396.0	347.4	409.3	268.1	345.0	355.6	290.6	337.1	260.3		3389.1
BFVOL 8.0:												
INITIAL	0.0	0.0	0.0	54.8	510.7	517.1	1028.6	1451.9	2015.4	2883.0	3579.3	-----
CUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
RESIDUAL	0.0	0.0	0.0	54.8	510.7	517.1	1028.6	1451.9	2015.4	2883.0		-----
MORTALITY	0.0	0.0	0.0	0.0	56.8	26.6	0.0	0.0	27.9	28.3		139.6
NET GROWTH	0.0	0.0	54.8	455.9	6.4	511.5	423.3	563.5	867.6	696.2		3579.3
GROSS GROWTH	0.0	0.0	54.8	455.9	63.3	538.1	423.3	563.5	895.5	724.5		3718.9
BFVOL 6.0:												
INITIAL	0.0	0.0	285.6	633.6	1355.3	1599.7	2307.2	3570.2	4745.8	6373.9	7739.3	-----
CUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
RESIDUAL	0.0	0.0	285.6	633.6	1355.3	1599.7	2307.2	3570.2	4745.8	6373.9		-----
MORTALITY	0.0	0.0	0.0	0.0	80.1	58.6	0.0	0.0	104.2	149.9		392.7
NET GROWTH	0.0	285.6	348.0	721.7	244.3	707.5	1263.0	1175.5	1628.1	1365.4		7739.3
GROSS GROWTH	0.0	285.6	348.0	721.7	324.4	766.1	1263.0	1175.5	1732.3	1515.2		8131.9

OAKSIM also allows considerable flexibility in calculating tree volumes. Merchantability standards may be specified. Two top d.i.b.'s for cubic volume and two top d.i.b.'s for board-foot volume calculations are specified by the user. Minimum lengths for both cubic and board-foot volumes may also be specified. Default values are 4.0 and 8.0 feet, respectively. The appropriate height prediction equation (either white or black oak) and bark ratio equations for each species group are assigned by the user.

The thinning option is initiated by user input. A list of the stand ages (initially or at any 5-year interval) and the desired percent stockings after thinning is all that is required.

Program output is also controlled by user input. Stand and stock tables for initial and final conditions are always printed (Table 1). The user may, however, elect to have all intermediate stand tables, stock tables, or both printed. The final summary table is always printed.

Growth Components

Diameter Growth

A distance-independent, individual-tree diameter growth model (Hilt 1983) is used in OAKSIM. The random variation of the model is used to allow trees within a given stand to change position over time. The mean 5-year basal area growth (BAG5YR) of an individual tree is predicted with the following equation:

$$BAG5YR = BETA*DBH**2 \quad (1)$$

where

$$BETA = (6.96762087*10**(-6))*(SI**1.5731724)*EXP(-.11839854*DBAR-.01198244*PS) \quad (2)$$

SI is the site index, DBAR is the quadratic mean stand diameter, PS is the percent stocking of the stand, and EXP is the base of the natural logarithms. All calculations in OAKSIM are made with double precision arithmetic.

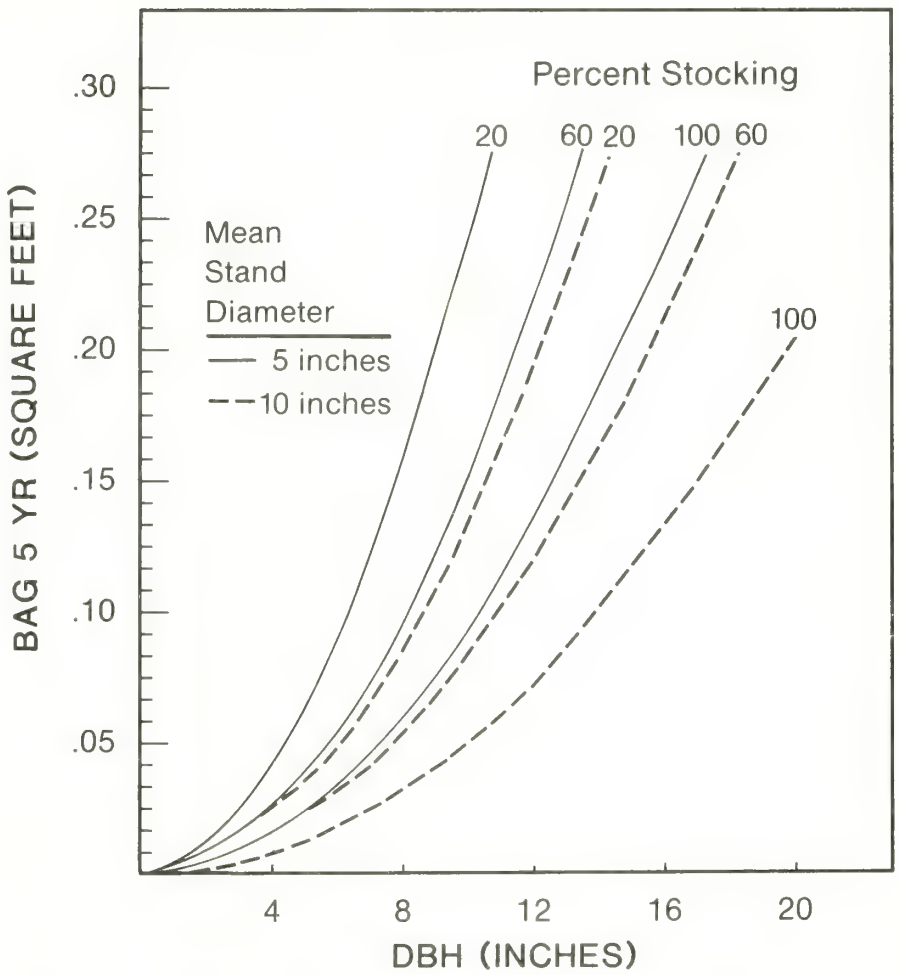

Figure 3.--Predicted 5-year basal-area growth rates (BAG5YR) for site index 70.

Equations (1) and (2) are used to predict growth for all tree species in a stand. The tree size variable, DBH, also accounts for growth differences among species. In other words, big trees grow faster--regardless of species. Trees in the black oak group (black, scarlet, and northern red) usually are larger, and therefore grow faster, than white and chestnut oaks in the same stand. The equations are applicable, however, only in stands where tree size differentiation has already occurred--stands at least 30 years old. Growth rates for other species that normally associate with upland oaks, such as dogwood, red maple, and yellow-poplar, can also be safely predicted with these equations as long as they are not the major component of the stand (see Program Applications). Bigtooth aspen, an unusually fast grower, would probably be slightly underestimated. Predicted growth rates for a range of stocking and mean stand diameter conditions are shown in Figure 3 for site index 70.

The standard deviation (SIGMA) of the mean 5-year basal area growth for a given tree is calculated as follows:

$$SIGMA = 0.00915129*EXP(0.12639572*DBH) \quad (3)$$

A random number generator is then used to generate a random number (Z) from a normal distribution with mean = 0 and variance = 1. The random growth rate (X) about the mean growth (BAG5YR) for a given tree is then calculated as:

$$X = Z*SIGMA + BAG5YR \quad (4)$$

The random 5-year basal area growth rate is then converted with appropriate arithmetic to 5-year diameter growth.

Equations 1 through 4 are used to predict diameter growth rates for the first 5-year projection. Diameter growth rates for successive 5-year projections are made with a random number draw from a conditional mean growth and a conditional standard deviation based on the bivariate normal distribution (see Hilt 1983). The conditional equations are based on values from equations 1 through 4 for both the 5-year period of interest and the previous 5-year period. Use of the bivariate normal approach guarantees that fast-growing trees have a higher probability of remaining fast growers, and slow growers will remain slow growers.

Mortality

The probability of mortality (PMORT) for an individual tree is determined at the beginning of each 5-year projection with the following logistic function:

$$PMORT = 1.0/(1.0+EXP(B0+B1*DBH+B2*DGROW)) \quad (5)$$

where DGROW is the periodic annual diameter growth of the tree for the past 5 years. Variations in mortality due to site, age, and stocking for a given size tree are accounted for with the DGROW variable. If PMORT is calculated to be less than 0.001, then PMORT is assigned the value 0.001. This assignment of a small probability of mortality accounts for fast growing and very large trees that die occasionally at random times for no apparent reason. Predicted, rather than past, diameter growth rates are used for DGROW during the initial 5-year projection because past growth is hardly ever known initially. A random number between 0 and 1, drawn from a uniform distribution, is used to decide whether the tree dies. If the random number is less than PMORT, the tree is considered dead and removed from the list.

Only one diameter growth equation is required for all species, but several are required for mortality. For example, oak trees in the black oak group usually have a higher probability of mortality for a given d.b.h. than oak trees in the white oak group. Equation (5), therefore, was fitted to data from four species groups: (1) white oak, (2) black oak, (3) other trees (primarily hickory), and (4) understory species such as dogwood and sourwood. Coefficients in equation (5) for each group are listed in Table 3. PMORT is plotted over DGROW by DBH classes for the white oak group in Figure 4.

Table 3.—Coefficients for mortality model (equation 5): PMORT = 1.0/(1.0+EXP(B0+B1*DBH+B2*DGROW))

Species Group	B0	B1	B2
White oak[a]	-1.99	0.356	66.58
Black oak[b]	-2.48	.312	34.83
Other trees[c]	-.183	.246	57.35
Understory[d]	.341	.132	29.59

[a]White and chestnut oaks
[b]Black, scarlet, and northern red oaks
[c]Hickory, red maple, yellow poplar
[d]Dogwood, sourwood, sassafras, serviceberry, shrubs

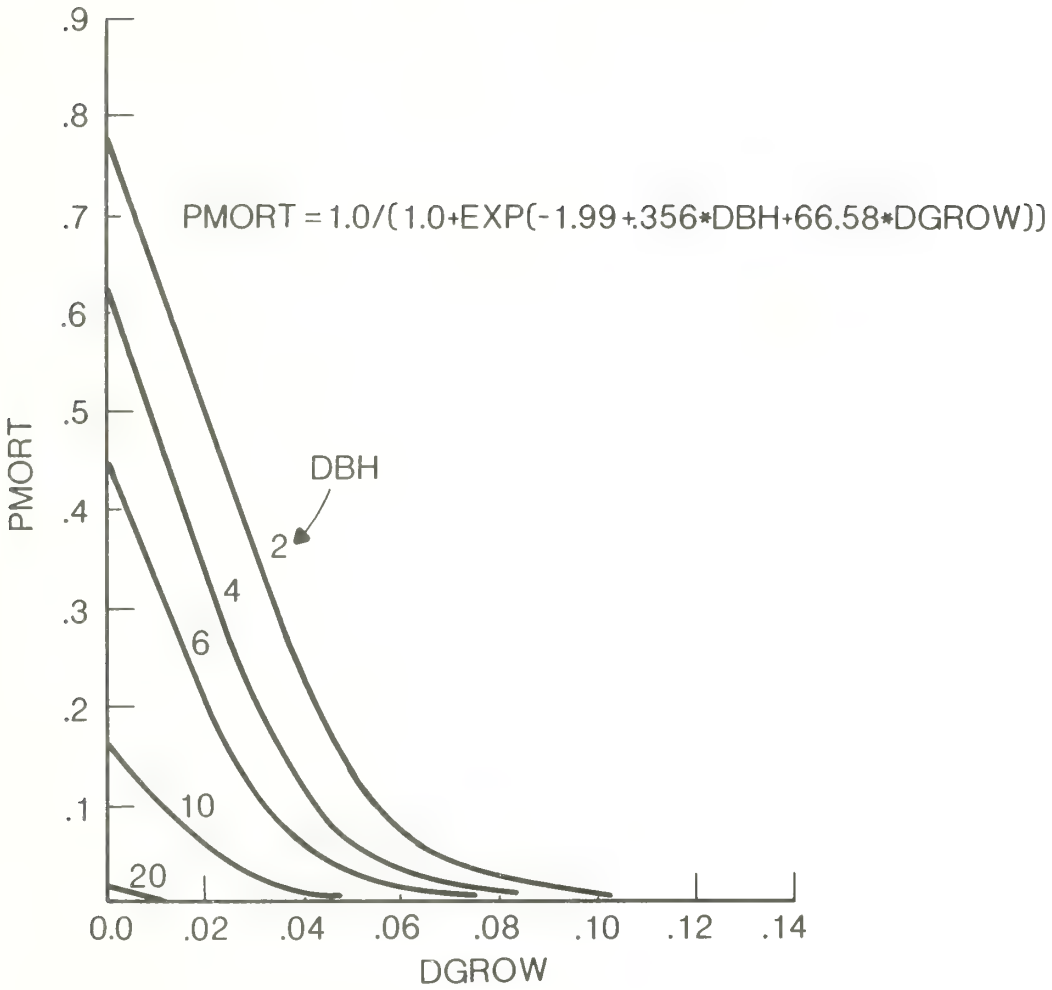

Figure 4.--Individual-tree probability of mortality (PMORT) for white oak group. DGROW is periodic annual diameter growth.

Calibration

Background

Calibration is the act of adjusting the simulator to meet actual growth and yield situations. Theoretically, all one must do is combine the diameter growth and mortality equations 1 through 5, and the simulator will function for all age, site, and stand conditions. Unfortunately, this is seldom the case. Nearly all major simulators designed to handle a wide range of applications have required some modification. Modification is necessary with individual-tree simulators because the probability of mortality is dependent on growth, and growth in turn is dependent on the stocking after dead trees have been removed. Sometimes slight modelling errors become cumulative and cause longer projections to go astray. Modification is also necessary because not all variations in a growth and yield projection are completely accounted for by the growth models.

OAKSIM was calibrated by comparing growth and yield projections with four sources of information: (1) actual growth and yield data from the managed stands discussed in the Data section, (2) upland oak yield tables for unmanaged stands prepared by Schnur (1937), (3) stand level projections made with GROAK (Dale 1972), and (4) personal experience. Although statistical validation tests have not yet been made, numerous comparisons with the 20-year managed stand data were performed. Longer projections of 50 years for unmanaged stands were compared with Schnur's tables up to age 80. Very few stands over age 80 were included in Schnur's tables for the simple reason that they did not exist in 1937. GROAK, a stand-level growth and yield model developed from the same managed stands used for OAKSIM, provided excellent comparisons for overall stand growth to age 100. Personal experience provides the added element of "feel" for whether the projections are realistic.

There are basically five components that need careful consideration for the calibration of an individual-tree simulator: (1) stand basal area growth (net and gross), (2) number of trees (live and dead), (3) minimum and maximum diameters of trees in the projected stand, (4) distribution of trees over d.b.h., and (5) relative proportions of trees by species groups. Most other stand components, such as mean stand diameter and percent stocking, will follow accordingly if these five components are correct. Volume, which also should follow accordingly, was not considered during the calibration of OAKSIM because tree volumes, as discussed later, are assigned to trees after the projection has been made.

Modifiers

Net periodic annual basal area growth (BAG) for a given stand is first predicted with the following equation from GROAK;

```
BAG = BA*AGE**(-.8)*LOG(BA)
+ .68521*BA* AGE**(-.75)
+ .011383*BA*SI*AGE**(-1.05)   (6)
```

where BA is the stand basal area, and AGE is the stand age. This equation is incremented five times to arrive at the net 5-year basal area growth for the stand. Individual-tree basal area growth rates from (4) are then multiplied by a constant, k, until the net stand basal area growth is within 2 percent of the growth predicted with GROAK. The value of k must be determined iteratively because net growth is the difference between gross growth for the 5-year period (growth of all survivor trees; Husch et al. 1972) and trees removed from the list with the mortality model. Many simulators use stand-level modifiers to adjust individual-tree growth rates, and GROAK is a wise choice for upland oaks because it has been extensively and successfully applied over a wide geographic area of the upland oak timber type.

After stand growth was calibrated, the total number of trees per acre and the relative number of trees in each species group required some adjustment, particularly over site index. This adjustment is made with a reassignment of PMORT from equation (5):

```
PMORT = PMORT*0.8                (7)
```

for the black oak group, and

```
PMORT =
      PMORT*(0.5 + 0.025*SI)     (8)
```

for all other species groups. Equation (7) simply lowers the probability of mortality for black oak for all conditions, and equation (8) increases the probability of mortality with increasing values of site index for the other species groups. The probability of mortality for a black oak tree of a given d.b.h. still remains higher than other species for most circumstances.

Minimum and maximum diameters, and also the distribution of trees in the projected stand, are adjusted with the reassignment of SIGMA from equation (3):

```
SIGMA = SIGMA*(1.88945
   -.07837*SI + .00087*SI**2)    (9)
```

Variation in tree growth for a given d.b.h. was found to increase with increasing site index. Equations (1) through (5) and the appropriate modifiers in equations (6) to (9) expand OAKSIM's application to a wider range of site index conditions than those available in the 20-year managed stand data base.

Volume Computation

Tree Height

Individual-tree volumes in OAKSIM are based on four components: (1) tree d.b.h. and species (available from the projected tree list), (2) height equations, (3) taper equations, and (4) bark ratio equations. Total tree heights (HT) are assigned to individual trees at each 5-year interval with equations developed for upland oaks by Hilt and Dale (1982):

$$HT = 4.5 + B0*(1.0 - EXP(B1*DBH)) \quad (10)$$

where model coefficients B0 and B1 are based on stand age and site index. Height prediction equations are available only for trees in the white and black oak groups. Until height prediction equations for other species groups can be developed, either the white or black oak equation must be used. Errors that arise from this circumstance are not considered major because the tree size variable, DBH, again accounts for a considerable portion of the species effect. Equations for the black oak group for site index 60 are shown in Figure 5.

Taper Equations

Diameters inside bark (DIB) up the stem are calculated for individual trees with the taper equation developed by Hilt (1980):

$$(DIB/DOB)^2 = X^{1.5} + .003040(X^{1.5}-X^3)*HT + .000226(X^{1.5}-X^3)*DBH*HT + .003210(X^{1.5}-X^{30})*DBH - .000212(X^{1.5}-X^{30})*DBH*HT \quad (11)$$

where X = (HT-h)/(HT-4.5), and h = height at measurement point (feet). The same taper equation is used for all species. Trees must be at least 2.6 inches in d.b.h. Sample tree profiles generated with (11) are shown in Figure 6.

Bark Ratio

The ratio of DIB to DOB up the stem is estimated for each tree with the equation developed by Hilt et al. (1983):

$$DIB/DOB = B0+B1*(DOB/DBH) \quad (12)$$

Values of the model coefficients, B0 and B1, for 10 species groups are listed in Table 4. The DIB/DOB ratio either remains constant or decreases up the stem for all 10 groups. If a mean DIB/DOB ratio at breast height (RBAR) is available, then B0 is set equal to the quantity (RBAR-B1) to adjust the ratios to local conditions. Equation (12) is plotted in Figure 7 for white oak, chestnut oak, and black cherry.

Table 4.--Coefficients for bark ratio model (equation 12):

DIB/DOB = B0+B1*(DOB/DBH)

Species	B0	B1
White oak	0.881	0.056
Chestnut oak	.774	.149
Black oak	.832	.103
Northern red oak	.864	.084
Southern red oak	.888	.040
Black cherry	.934	.017
Yellow-poplar	.840	.087
Red maple	.919	.045
Sugar maple	.873	.017
American beech	.931	.025

Program Execution for Volume

Appropriate tree height and bark ratio equations are assigned to each species group by the user. Total height is then assigned to a tree based on the projected d.b.h., the age and site index of the stand, and the species group to which the tree belongs. Heights (h) to user-specified top d.i.b.'s are then calculated with a bisection algorithm. Minimum merchantable lengths specified by the user must be met, or no volumes will be calculated. Default values are 4.0 feet for cubic volume and 8.0 feet for board-foot volumes. The merchantable portion of the stem is then divided into 50 equal segments, and the d.i.b. and d.o.b. at each section point are calculated with (11) and (12). Cubic volumes of each section are calculated as truncated cones and summed to obtain volumes inside and outside bark for the tree. A 1-foot cylindrical stump is also included in cubic volume values. Board-foot volumes are calculated from 16-foot logs with the International 1/4-inch rule. Fractions of logs are included if they are not exactly 16 feet.

Thinning Rule

The thinning rule used in OAKSIM is based on a mathematical model derived from the actual thinned plots discussed in the Data section. Complete development of the model will be documented in a forthcoming publication. The model has the following form:

$$CUTFRQ(I) = 1.0 - EXP(-1.77980*CUMFRQ(I) + .019849*CUMFRQ(I)*THINPS) \quad (13)$$

where CUTFRQ (I) is the cumulative frequency of the trees to be cut in the ith d.b.h. class divided by the total number of live trees in the stand, CUMFRQ (I) is the cumulative relative frequency of the live trees in the ith d.b.h. class, and THINPS is the percent stocking desired after thinning. For example, if a thinning to the 40 percent residual stocking level were desired in a stand with 500 total stems and 100 stems in the 3-inch d.b.h. class, CUMFRQ (3) would equal 0.20, CUTFRQ (3) would equal 0.18, and the resulting number of

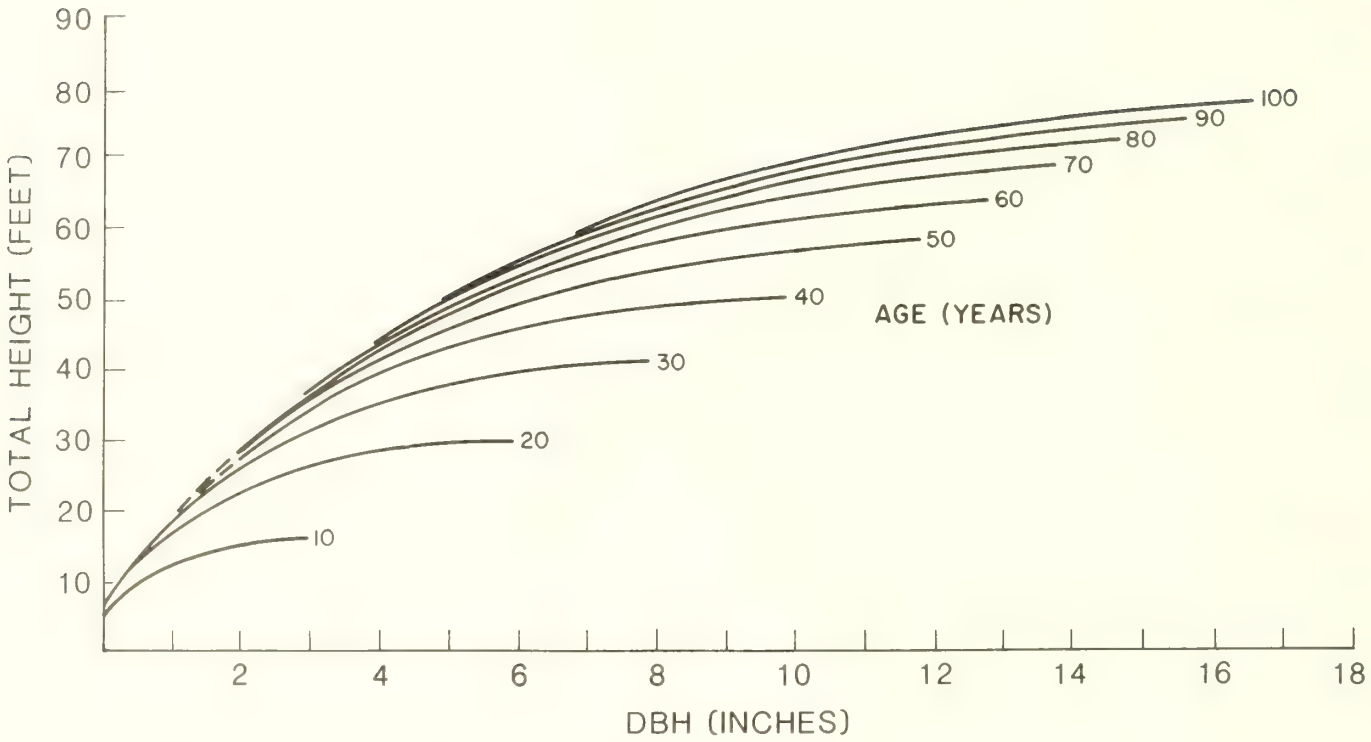

Figure 5.--Height-diameter-age curves for black oak, site index 60.

trees to be removed in the 3-inch class would be equal to 0.18*500 = 89. Age and site index did not have a significant effect on the thinning rule. Equation (13) is plotted in Figure 8 for a range of THINPS values.

The thinning rule makes every attempt to duplicate the actual thinning method applied by professional foresters in managed upland oak stands. OAKSIM is one of the few simulators that uses a thinning rule based on actual data, not artificial rules governed only by computer programming. Until additional plots can be established to study other thinning methods in upland oak stands, such as thinning strictly from above or below, this thinning rule should be used because the growth models are based on this thinning method. There is, however, some flexibility with OAKSIM. Three options are available for distributing cut trees across species groups within a d.b.h. class: (1) maintain the same proportion of species as the unthinned stand, (2) double the allocated cut for specified species groups, and (3) eliminate specified species groups entirely. Only minor species groups such as understory species should be eliminated with the third option. Major species groups such as white oak or black oak should not be eliminated.

OAKSIM uses an iterative application of the thinning rule to insure that all d.b.h. and species groups are thinned accordingly. Two or three passes through the tree list are generally required to reduce the stand to the desired THINPS.

Random Number Generator

A random number generator is used in OAKSIM to convert stand tables to tree lists and to calculate individual-tree diameter growth rates and probabilities of mortality. A random number (U) is drawn from a uniform distribution between 0 and 1. This number is used unaltered to construct tree lists and calculate the probability of mortality, but is converted to a normal deviate (XNORM) from a distribution with mean = 0 and variance = 1 with the following equation for diameter growth calculations:

$$XNORM = SQRT(-2.0*LOG(U1)) *COS(6.283*U2) \quad (14)$$

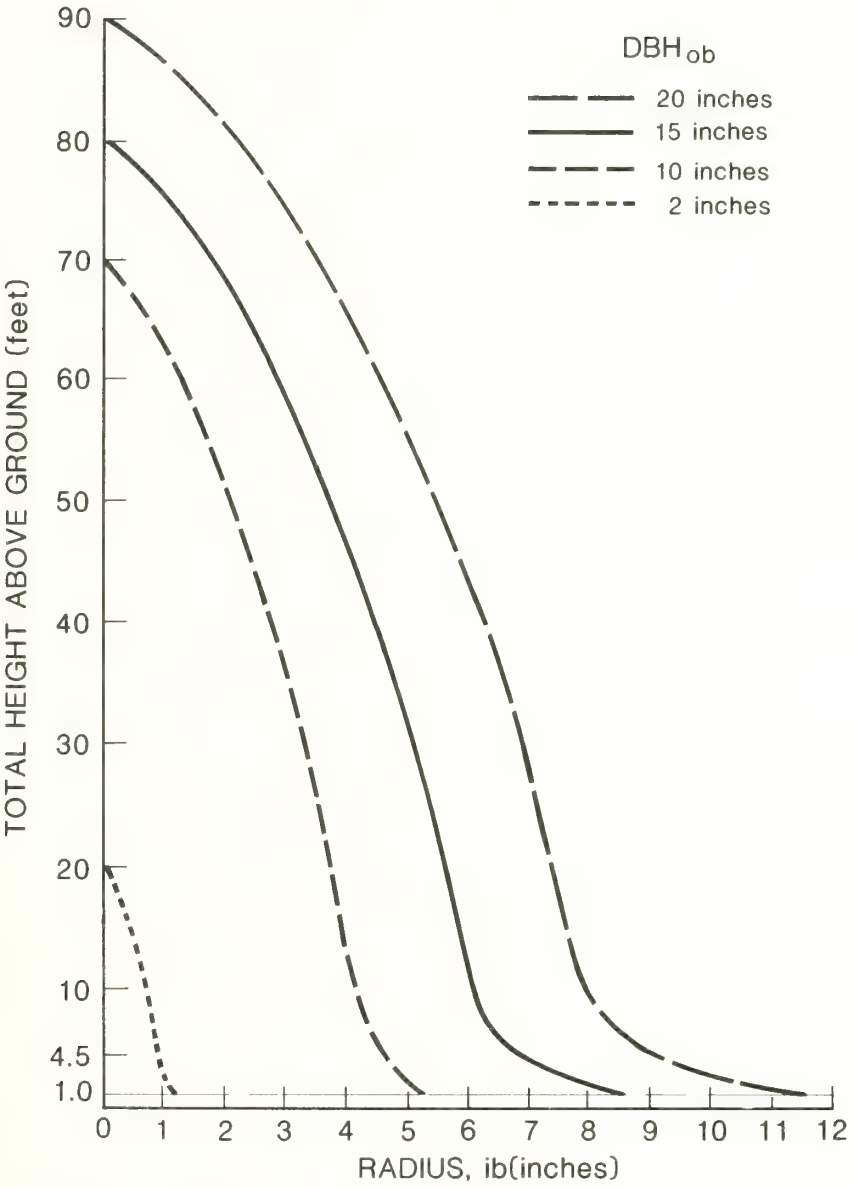

Figure 6.—Sample stem profiles generated with taper equations used in OAKSIM.

where U1 and U2 are random numbers drawn on successive occasions. The CALL statements in OAKSIM used to invoke the random number generator are based on local computing commands, and will require some modification by the user. The generator used in OAKSIM is almost identical to IBM's RANDOM Subroutine Package. If RANDOM or its local counterpart are not available, users are advised to use a well-tested random number generator.

Use of random numbers makes OAKSIM a stochastic simulator. Output is somewhat dependent on the random numbers generated and can be altered by changing the seed used to initialize the generator (although this is not recommended). The seed statement in OAKSIM is IX = 111111. Testing has revealed that changing the seed, and hence the sequence of random numbers, changes the output only slightly, especially if long projections such as 50 years are specified. Slight variations in output reflect only the natural variation inherent in the complex growth and yield of a forest stand.

Example Using OAKSIM

Bracketed numbers in this section refer to annotations on the OAKSIM output in Tables 1 and 2. Output for a young white oak stand in Kentucky that was thinned to 40 percent stocking with OAKSIM appears in Table 1. Only the final summary table of the unthinned OAKSIM run for the same stand is shown in Table 2.

Control cards supplied by the user indicate that stand table input is being used for a stand that is 34 years old on site index 66 [1]. Tree volumes are desired for 4.0 and 0.0 d.i.b. tops for cubic volumes, and 8.0 and 6.0 d.i.b. tops for board-foot volumes [2]. Default values of 4.0 and 8.0 feet are used for minimum merchantable lengths of logs. Trees between 4.6 and 8.6 will be classified as poles. A sawtimber threshold d.b.h. of 8.6 inches was used in this example only so readers can make comparisons with Schnur's (1937) yield tables and Dale's (1972) GROAK projections. A threshold d.b.h. of 11.6 inches for sawtimber would be more common.

Volume computations and program output will also depend on the assignment of tree species codes to a species group, and the subsequent assignment of a height and bark ratio prediction equation to that species group [3,4]. Species group 1 in this example consisted entirely of white oaks, group 2 was black and scarlet oak, group 3 was hickory and red maple, and group 4 was shrubs, such as dogwood and sourwood.

A total of ten 5-year projections are to be made, with one initial thinning to 40 percent stocking [5,6]. All intermediate stand tables are requested, but no intermediate stock tables are desired.

The initial stock table for age 34 [7] includes a comprehensive break-

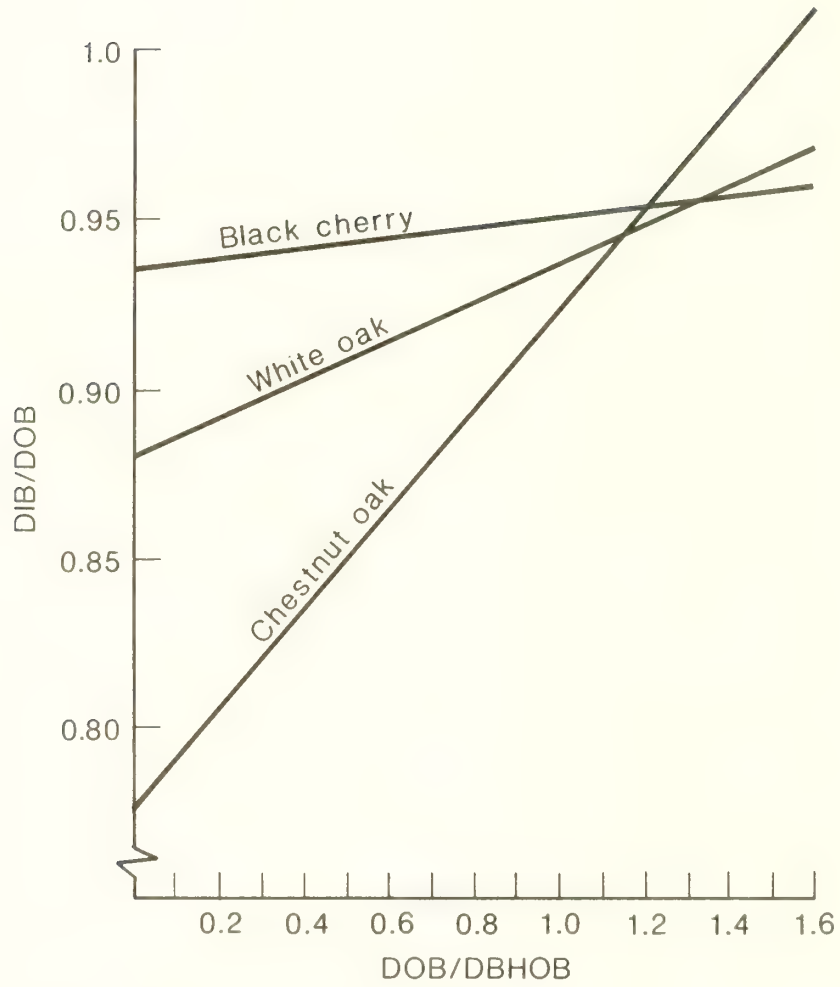

Figure 7.—DIB/DOB ratios for three species.

down by species groups and size classes for all major stand characteristics. Average d.b.h. [8] values listed in the stock tables are arithmetic means, not quadratic. The initial stock and stand [9] tables are always printed. Since all intermediate stand tables were requested for this run of OAKSIM, stand tables for trees removed in thinning [10], residual trees after thinning [11], mortality trees [12], and trees in the projected stand [13] for all 5-year intervals are printed (only those to age 39 are listed in Table 1). Final stand [14] and stock tables [15] are always printed.

It is evident from [10] that the majority of the 440 trees removed in the "free" thinning applied with the thinning rule (equation 13) were in the lower crown classes. Nearly 80 percent of the trees in the 3-inch class were cut. Some of the largest trees, however, were also removed. These larger trees are representative of the larger cull and rough trees often found in most stands. The percentage of trees by species group in each d.b.h. class, as specified with the control cards [6], remained nearly the same after thinning.

All of the detailed information available in the stand and stock tables must be utilized for a comprehensive evaluation of various thinning regimes. The size and species determine the value of a tree. For example, the changes that occurred in the white oak group should be examined closely because of the high value of this species relative to the other three groups. On the other hand, the final summary tables [16,Table 2] provide a good overall look at stand development over the projection period and is most useful for narrowing the choices of various thinning regimes.

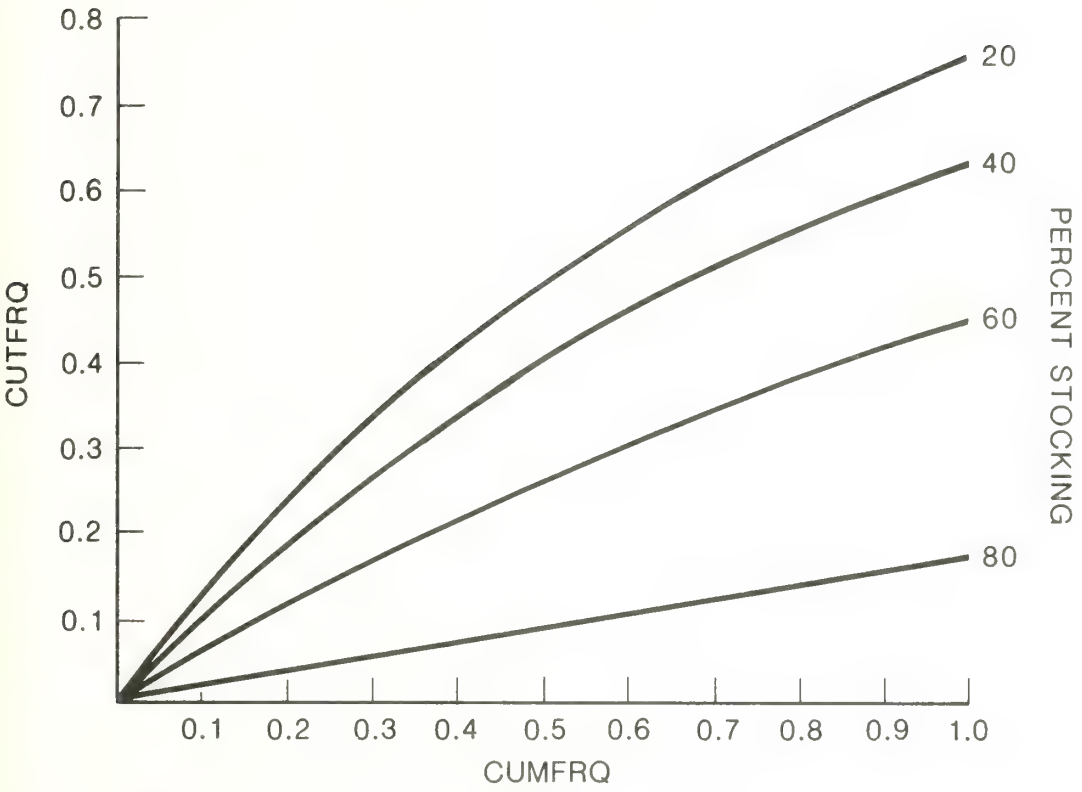

Figure 8.—Thinning rule depends on cumulative frequencies of cut trees and live trees before cut. See text for definitions of CUTFRQ and CUMFRQ.

Basal area, total cubic-foot volume inside bark, and board-foot volume growth and yield information extracted from [16] and Table 2 are plotted in Figure 9. Gross growth for the 50-year projection was reduced in the heavily thinned stand—88.7 square feet of basal area growth, compared to 104.7 for the unthinned stand, and 3017 cubic feet compared to 3389. Net growth, however, showed a marked increase in the thinned stand. Net basal area growth for the thinned stand was 69.5 square feet; in the unthinned stand, it was only 45.7. Net cubic volume growth was 2544 cubic feet, compared to 2133. Mortality was sharply reduced with thinning, particularly for the first 25 years after thinning. Board-foot growth and yield increases from thinning are dramatic at age 84: the thinned stand had 32 percent more board-foot volume in trees 8.6 inches d.b.h. and larger. This difference was due not only to the increased diameter of the thinned trees, but also to the fact that the thinned stand had 126 trees in the sawtimber size class compared to only 113 trees for the unthinned stand.

Even though gross growth rates are reduced somewhat by thinning this stand to 40 percent stocking, gains in net growth and board-foot yields indicate that a heavy thinning at age 34 is still a viable option. This run of OAKSIM also suggests another alternative: to thin initially to 40 percent and thin again at age 59 to perhaps 60 percent, since mortality started to increase at that age.

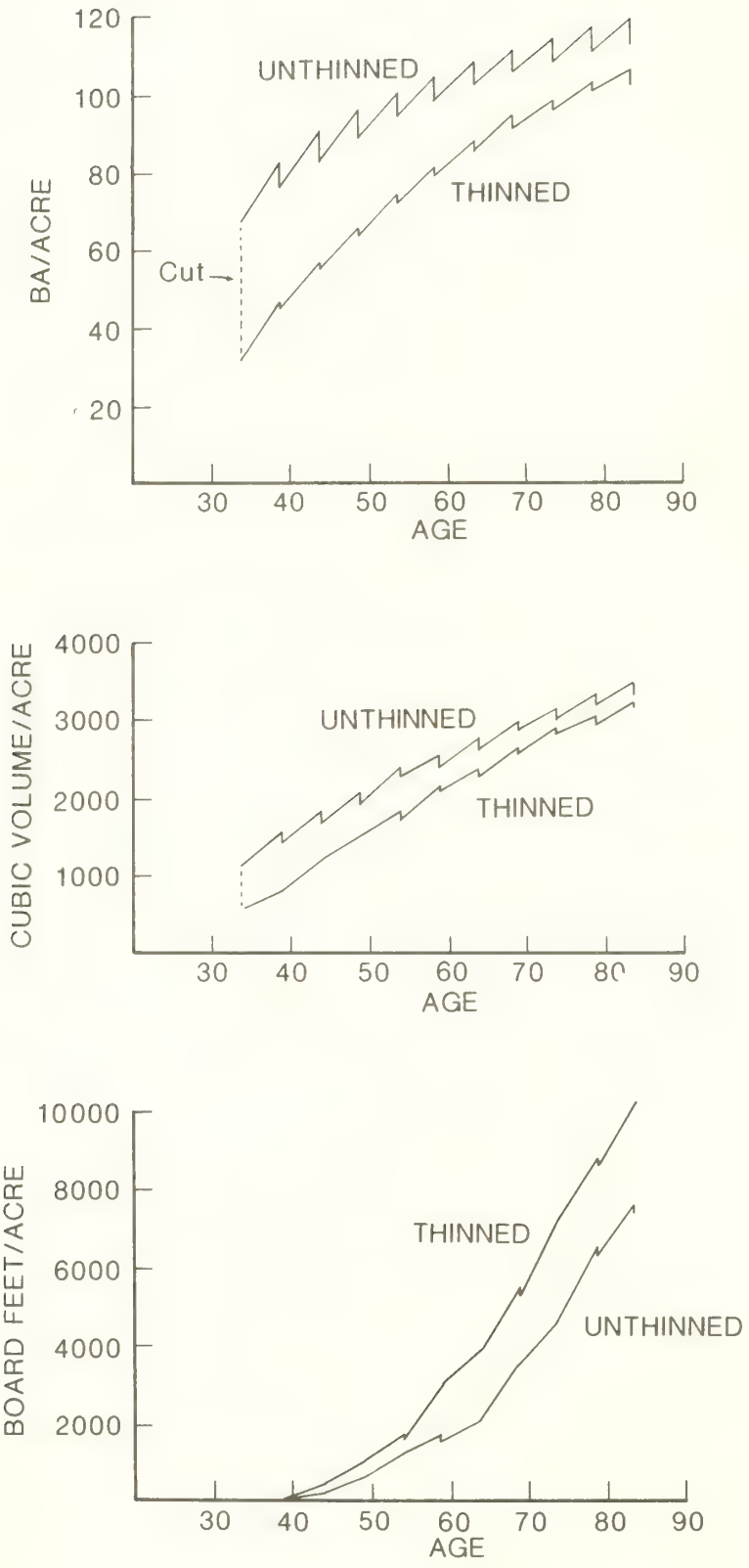

Figure 9.--Basal areas, cubic volumes (total stem inside bark), and board-foot volumes (all trees 8.6 inches and larger to a 6 inch top) per acre for sample run of OAKSIM.

Discussion

This initial version of OAKSIM is applicable to a wide range of age, site, and stocking conditions for a large portion of the upland oak timber type. The ultimate goal is to produce a complete simulator capable of generating the entire growth cycle--not only growth of the present stand, but also ingrowth and regeneration. Ingrowth can be substantial in heavily thinned upland oak stands. And stump sprouts from ingrowth trees will most likely determine the species composition of the next stand after the rotation harvest cut. Timber management planning for the current rotation, however, should be based primarily on those trees already covered by this version of OAKSIM, not on ingrowth trees.

Future enhancements planned for OAKSIM should also encourage application of the simulator. Computer programming statements will be added to allow input from variable-plot (prism) timber cruises. This will eliminate the need for users to construct their own stand tables for input into OAKSIM. A microcomputer version of OAKSIM will also give more users access to the simulator.

This version of OAKSIM has been rigorously tested. Its net stand basal area growth is compatible with that of the previously developed stand growth and yield simulator, GROAK. However, a complete statistical validation of OAKSIM is also planned, primarily for the purpose of placing error limits on the growth and yield projections. Some measure of accuracy of the simulator is essential for large-scale applications.

OAKSIM is available from the author upon request. The program consists of approximately 1700 statements, and should be compiled to save computing costs. Control statements and data can be stored in a separate data file and read during execution. Use of a CRT screen and a text editor language package maximizes the program's flexibility. The ages and intensities of thinning can be changed easily to test a variety of management alternatives. Execution time on the AMDAHL 470 V/6 computer is approximately 10 seconds for a 50-year projection for one stand. Complete operating instructions for OAKSIM will be published in a user's guide.

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OAKSIM is an individual-tree growth and yield simulator for managed, even-aged, upland oak stands. Growth and yield projections for various thinning alternatives can be made with OAKSIM for a period of up to 50 years. Simulator components include an individual-tree diameter growth model, a mortality model, height prediction equations, bark ratio equations, a taper-based volume system, and a mathematical thinning rule based on actual data. OAKSIM can be applied to a wide range of age, site, and stand conditions to develop management (thinning) guidelines.

ODC: 242 : 561 : 562 : 564 : 567 : 568 : 612

Keywords: Increment; thinning.

*U.S. GOVERNMENT PRINTING OFFICE: 1985-505-028:20026

Headquarters of the Northeastern Forest Experiment Station are in Broomall, Pa. Field laboratories are maintained at:

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United States
Department of
Agriculture

Forest Service

**Northeastern Forest
Experiment Station**

Research Paper
NE-563

1985

OPTIGRAMI: Optimum Lumber Grade Mix Program for Hardwood Dimension Parts

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Abstract

With rapidly increasing lumber prices and shortages of some grades and species, the furniture industry must find ways to use its hardwood lumber resource more efficiently. A computer program called OPTIGRAMI is designed to help managers determine the best lumber to use in producing furniture parts. OPTIGRAMI determines the least-cost grade mix of lumber required to produce a given cutting order of dimension parts. If the optimum grade mix is not available, the program can determine the best alternatives. It also can be useful in procurement and allocation planning. A description of the program and examples of its use are included.

Introduction

As mid-1984 arrived, lumber prices for No. 1 Common 4/4 plain-sawed northern red oak topped $600 per thousand board feet (M bf). The FAS grade, with premium, topped $950 per M bf. Cherry and tough ash were not far behind.

With spiraling lumber prices and shortages of some grades and species, the furniture industry must find ways to improve efficiency of lumber use. A computer program called OPTIGRAMI is a management tool that can do just that. With it you can determine the optimum, or least-cost, mix of lumber grades required to produce a given cutting order in a furniture rough mill; if this mix is not available, the next best mix can be determined. OPTIGRAMI also can be used in making decisions on improving lumber use practices.

In this paper, I discuss the OPTIGRAMI program and provide examples of how the program can be used to help solve day-to-day rough-mill decisions. Another report entitled "OPTIGRAMI Users' Manual" provides the users of OPTIGRAMI with step-by-step instructions for performing an analysis. It can be obtained from the Northeastern Forest Experiment Station's Forestry Sciences Laboratory, P.O. Box 152, Princeton, West Virginia 24740; or from the USDA Forest Service's Northeastern Area, State and Private Forestry, 370 Reed Road, Broomall, Pennsylvania 19008.

OPTIGRAMI

OPTIGRAMI is a computer program that was written for the person with little or no computer experience. Input to the program is straightforward and includes numerous prompts for the user's benefit.

Because the program is designed for use on any IBM mainframe computer with a mathematical programming system (MPS) in its program library, access can be through an on-site computer or through a remote terminal.

For users wishing to use a remote terminal, OPTIGRAMI has been placed on the Computerized Management Network (CMN), a national time-sharing computer service managed by the Virginia Cooperative Extension Service. The CMN software library consists of many problem-solving programs and resides on the computer at Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Access to CMN can be made with any ASCII terminal and a modem. You also can use a microcomputer with a communications program as a terminal. You can access CMN by dialing the computer directly and paying the long-distance charges on your monthly telephone bill.

Anyone can use CMN. Directions for obtaining a CMN userid and password are presented in the OPTIGRAMI Users' Manual.

For its data base OPTIGRAMI uses the predicted yields of dimension parts from standard grades of kiln-dried lumber developed at the USDA Forest Service's Forest Products Laboratory (Englerth and Schumann 1969). These yields were developed for hard maple, but they can be applied to most species graded by the same standard National Hardwood Lumber Association rules.

OPTIGRAMI uses linear programing techniques to correlate the input cost for each lumber grade with the predicted yields of various dimension part sizes to determine the least-cost combination of grades required to satisfy a given cutting order. The sensitivity of that combination to changes in the cost associated with each grade also is evaluated.

The OPTIGRAMI printout provides detailed information on production cost, yields by grade, and the size, number, and net board footage of cuttings obtainable from each grade.

The program is fast, simple to use, and inexpensive, usually costing less than $5 per analysis. It provides a quantitative basis for making decisions based on input information applicable to each specific situation.

Information Required

The only input information required is a description of what you want OPTIGRAMI to evaluate. In general, this consists of the cutting order to be evaluated; the grades of lumber you want considered and costs for each; and any conditions or limitations you may impose.

Cutting Order Information

Cutting order information typically includes some type of identification or furniture model number; the date and species for future reference; the thickness of lumber required; and the cutting order itself, which is a listing of the cuttings by length, width, type, and number required. Up to 50 different sizes of cuttings can be evaluated at one time. The yield tables accommodate lengths from 10 to 96 inches and specified widths up to 6 inches. A random-width description is used when the parts are to be glued into panels.

Lumber Grades and Costs

You can select up to three grades of lumber to be considered for possible inclusion in the least-cost mix. These can be picked from First and Seconds (FAS), Selects (SEL), No. 1 Common (No. 1 C), No. 2 Common (No. 2 C), or No. 1 Common and Better (No. 1 C and Better). The input cost for each grade, expressed in dollars per M bf, is the sum of all costs through the rough mill. Cost items to be included are at the discretion of the user but could include costs for lumber purchase, delivery, drying and handling, rough-mill cut-up, inventory, inspection, and overhead (Table 1).

Table 1.—Cost items to consider when determining production cost per lumber grade

Lumber grade	Purchase price	Delivery	Drying and handling	Cut-up	Inventory and storage	Overhead and other	Total
	Dollars/M bf						
2 C	292	20	100	80	8	70	570
1 C	588	20	100	50	10	75	835
FAS	768	20	100	40	12	80	1020

Volume Limitations and Yield Adjustments

The volume limitations and yield adjustments are simply options you can use to tailor the OPTIGRAMI analysis to fit your specific situation. You can limit the volume of a grade being considered by placing a volume constraint on that grade. The resulting OPTIGRAMI evaluation may or may not use all of the grade in limited supply; but in no case will the least-cost grade mix contain more of that grade than the volume allowed.

You also can adjust the predicted yields of any of the grades with a yield adjustment factor. Acting as multipliers, yield adjustment factors can be used to adapt the basic yields for individual species, admissible defects, heavy thicknesses of lumber, and general rough-mill efficiency.

What's the Best You Can Do?

The OPTIGRAMI printout consists of four sections: (1) the input information that you have evaluated; (2) the optimum of least-cost grade mix; (3) the range and sensitivity analysis; and (4) the cutting instructions to obtain the desired cuttings. The first three sections usually would be retained by the plant manager and filed for future reference. The last section would go to the rough-mill foreman for use in establishing the cutting instructions.

Input Information

The first section is strictly for reference purposes. It records the input information you have asked to be evaluated. Appendix I includes our cutting order identification, species, and date, and the grades we wanted evaluated, lumber cost, yield adjustment factor, volume constraints, and lumber thickness.

Next we have the cutting order that we have evaluated. The length, width, type, and number of pieces were input. The net board feet of each cutting was calculated by the program. The cutting bill does not need to be entered in any given order; the program will arrange it by type of cutting, whether random or specified, and by longest length first.

Least-Cost Grade Mix

The second section provides the least-cost grade mix solution (Appendix II). In addition to the cutting order identification, the printout shows which grades were being considered, the input cost for each grade, and the least-cost grade mix. The printout contains, for each lumber grade, the predicted lumber volumes required; each grade's contribution to the total production cost; the net board feet of cuttings; the percent yield; and the totals of these for the entire cutting order. In our example, the least-cost grade mix had a total cost of $14,538 and contained 7.268 M bf of No. 2C, 5.298 M bf of No. 1 C, and 5.855 M bf of FAS (Appendix II). For the conditions we have imposed, that is the best we can do. There is no other combination of grades that will result in a lower total cost.

Range and Sensitivity Analysis

The range and sensitivity section provides information on how responsive our optimum grade mix is to changes in the input cost of the various grades being considered (Appendix II). For decision purposes, it is probably the most important part of the OPTIGRAMI printout.

By varying the input cost of one grade while holding the others constant, OPTIGRAMI determines at what level of input cost there would be a change in how the grades are used to obtain the cuttings required. In essence, the program says that if the input cost of a given grade were to change to this new level, assuming that the cost of others remains the same, there would be another combination of volumes that would be as good as the least-cost grade mix we have now. In other words, at those input costs both volume combinations would have the same total cost. The program also calculates the amount of that grade that would be used in the alternative least-cost grade mix associated with that level of input cost.

Another way to consider these cost limits for a grade is that within the cost range between them, assuming that the cost of other grades remains constant, the least-cost grade mix will not change. True, the total cost will change depending on the level of input cost being considered; but the specific volumes of the grades given in the least-cost solution always will provide the lowest total cost for those conditions.

For example, consider the cost of No. 1 C in our range and sensitivity analysis (Appendix II). Although the input cost is $835.00 per M bf, it could range from a low of $834.23 to a high of $851.64 per M bf without changing the least-cost grade mix.

However, at an input cost of $834.23 per M bf, less than a dollar per M bf from our current cost, there would be another combination of grades with the same total cost, but it would use 10,281 board feet of No. 1 C. That is nearly twice as much as our current optimum mix.

In linear programing, the range values often are referred to as critical points, representing the intersection of two limiting constraints in the optimal solution. Consequently, they provide two equal solutions.

In our example, the alternate solution would use 4,983 board feet more No. 1 C. Since it must have the same total cost as the original grade mix, it stands to reason that it will use less of the other grades. Note that the associated volume for No. 2 C drops from 7,268 board feet to 5,785 board feet, and FAS drops from 5,855 board feet to 2,609 board feet.

By comparing the total cost for the two solutions, you can confirm their equality:

	No. 1 C	*No. 2 C*	*FAS*	*Total*
Current solution	($834.23 × 5.298)	+ ($570 × 7.268)	+ ($1020 × 5.855)	= $14,535
Alternative solution	($834.23 × 10.281)	+ ($570 × 5.785)	+ ($1020 × 2.609)	= $14,535

This particular cutting bill is sensitive to input price, especially that of No. 1 C. Information regarding the alternative grade mix can be of tremendous value to the rough-mill manager.

Cutting Information

The last section of the OPTIGRAMI printout is the cutting information for obtaining the required furniture parts from the proposed grade mix (Appendix III). This is the section that would be given to the rough-mill foreman. It provides the input volume of each grade according to the optimal grade mix, the part sizes that should be obtained from each grade, and the number of pieces that are expected from that volume of lumber.

This section also provides a value called "board feet shorts." In the case of No. 2 C, it shows 625 board feet, or the net board feet of volume that would be available in 10-inch-long, random-width cuttings. This value was included in the program to provide an indication of how well the resource is being used. In our example cutting order, the shortest length is 19-1/2 inches. Consequently, there would be substantial material available for 10-inch cuttings.

As you would expect, the longer pieces are from the better grades while the short pieces are from all grades. For our cutting order, all of the requirements for 87-3/4-inch, 80-3/8-inch, and 56-inch cuttings would be obtained from FAS, as would some of our shorter pieces.

The longest length to be obtained from No. 1 C would be 64-3/8 inches. However, the full requirement, 200 pieces, would be obtained from No. 1 C, as would the full requirement for the 48-1/4-inch random cuttings.

The requirements for the 33-1/8-inch cuttings were split between FAS and No. 1 C, and the 23-1/2-inch cuttings were split between No. 1 C and No. 2 C. The shortest two lengths would be obtained from all three grades. Information regarding specific lengths and number of pieces to be derived from each grade can have a major impact on improving yields from the raw material.

If You Can't Have Optimum, What Is Next Best?

Optimum is best, and we always would conduct as unconstrained OPTIGRAMI analysis as our first step. Because most furniture rough mills do not have unlimited supplies of every species, grade, and thickness, OPTIGRAMI is useful in helping the rough-mill manager allocate the available raw material most efficiently.

The key to determining the next best alternative for lumber allocation is the range and sensitivity analysis section. In general, when the upper or lower cost limit is near the current input cost and is accompanied by a major change in the associated gross volume, our least-cost solution would be considered sensitive. By contrast, if a major change in the input cost would result in a relatively minor change in the associated gross volume used in the alternative solution, our current solution would be considered relatively insensitive to the cost of that grade. Essentially, everyone would agree with these definitions of sensitivity at the extremes. However, between these extremes is a gray area of what is sensitive and what is not. Sensitivity is really a measure of what is of practical importance; it is at best a subjective judgment. As a result, changes in the total cost of our cutting order or in the volume of a grade of lumber used that seem important enough for us to take advantage of today might be considered a nuisance 6 months from now.

Use of the range and sensitivity analysis of OPTIGRAMI can be helpful in determining our next best alternatives when we have a limited supply of a grade, or are trying to conserve a grade that is in short supply, or have run out of a grade entirely.

Limited Supply of a Grade

With all of the different species, grades, and thicknesses required to operate a modern rough mill, occasionally there will be an insufficient supply of available dry lumber of a given grade and thickness needed for the least-cost grade mix. However, the fact remains that whatever other option we decide to take, the total cost will be greater than if we had the optimum mix of grades.

Certain types of cutting orders appear to have certain grades or grade mixes that are most appropriate for them. For instance, cutting orders for dining room chairs typically require a high proportion of No. 2 C in the least-cost mix. Buffets, on the other hand, call for mostly No. 1 C. An indication of the appropriateness of a given grade to a cutting order can be derived from the upper and lower cost limits in the range and sensitivity section. For example, if OPTIGRAMI has been used to evaluate a cutting order for dining chairs, the upper cost limit for No. 2 C might be $80 or $90 above the current input cost that was used. This would be interpreted to mean that if the cost of the other grades remains unchanged, the input cost level of No. 2 C could increase by $80 or $90 without changing the amount of the No. 2 C used in the least-cost solution. Therefore, No. 2 C would be considered well suited to this cutting order. In other words, this cutting order is insensitive to the cost changes of No. 2 C. It also means that if there is a shortage of No. 2 C, this would not be a good cutting order to be forced to substitute No. 1 C to fulfill the total lumber requirements.

Although OPTIGRAMI evaluates each cutting order individually, the printouts from these individual analyses can be helpful in making decisions that involve a number of cutting orders.

With this in mind, assume that we were evaluating the OPTIGRAMI solutions with unconstrained lumber volumes for three individual cutting orders that together required a total of 60 M bf of No. 2 C 4/4 pecan. From our inventory records we determined that only 40 M bf are available. Therefore, we must substitute some of our higher grades, probably No. 1 C, to complete the orders. Our problem becomes: Where can we substitute most effectively? By looking at the individual range and sensitivity analyses for No. 2 C, we note the following:

Cutting bill	*Input cost and levels*	*Associated gross volumes*
	Dollars/M bf	*M bf*
A	463.50	18
	410.00	20
B	497.25	28
	410.00	30
C	418.85	7
	410.00	10

Our logic would be as follows: On the basis of the upper limits shown, we might consider that No. 2 C could be worth as much as $497 per M bf to us relative to the costs of the other grades when it is being used in cutting order B. Consequently, cutting order B provides our highest value use of No. 2 C and should receive all of the No. 2 C it requires—30 M bf. In other words, B is the most insensitive to changes in the cost of No. 2 C and, therefore, least suited for substitution. Cutting order A would be next and should receive the remainder. However, since there is not enough No. 2 C to fulfill A's 20 M bf requirement, it should be reanalyzed by OPTIGRAMI but this time with a 10 M bf volume constraint on No. 2 C. OPTIGRAMI will then give the least-cost grade mix for A based on this limitation. Cutting order C is the most sensitive to the cost of No. 2 C, and OPTIGRAMI automatically would reduce the amount of No. 2 C used if the level of input cost increased by as much as $9 per M bf. Therefore, cutting order C should be reevaluated by OPTIGRAMI and not include No. 2 C in the grades to be evaluated. By using the 40 M bf of No. 2 C pecan in these combinations for the three individual cutting orders, our combined cost for all three will be at a minimum for the conditions that exist.

Conserving Grades in Short Supply

If a given grade and thickness of a species is expected to be in limited supply over a prolonged period, OPTIGRAMI can help determine ways to conserve it. In this case, each time an OPTIGRAMI evaluation indicates the use of this grade in the optimum mix, the range and sensitivity analysis should be examined for possible alternatives. If the analysis indicates that the optimum solution is sensitive (i.e., upper or lower cost limits are close to input cost), then that cutting order may be a good place to elect to substitute at least some of another grade and thereby conserve the one in short supply. By being sensitive, it points up the opportunity to be able to change the grade mix from optimum at a relatively small sacrifice in increased total cost. It is less costly in the long run to substitute some of another grade at each opportunity rather than to run out of a grade and then be forced to substitute in a cutting order that clearly is suited to the grade that is no longer available.

This is where sensitivity becomes subjective. How much are we willing to increase the total cost of a given cutting order to conserve a specific grade of lumber? In the case of our example cutting order, there would be little additional cost. As an example, suppose we wish to conserve No. 2 C. From the printout in Appendix II, we could determine that the next best grade mix would use 5.785 M bf of No. 2 C instead of 7.268 M bf. Since at the input cost of $572.59 per M bf both mixes would have the same total cost, we can determine that we could conserve 1,483 board feet of No. 2 C at a sacrifice of $3.84 in increased total cost. This is calculated by multiplying the change in input cost by the change in volume at the limit ([$572.59 − $570] × [7.268 − 5.785] = $3.84). Is it worth $4 to us to save 1,480 board feet of No. 2 C?

If it is, then we also might want to consider going beyond the limits of this OPTIGRAMI evaluation and rerun it with a constrained volume for No. 2 C below the current limit volume of 5.785 M bf. This would provide another alternative for saving the grade that we might wish to consider.

What Is Next Best if You Run Out of a Grade

When you are out of one of the grades contained in the least-cost mix, you should first rerun OPTIGRAMI, omitting this grade from those being considered, and then compare the total cost of the two evaluations. If the additional cost is not considered serious, then you have the next best solution.

If the additional cost is considered prohibitive, OPTIGRAMI can be used to help you evaluate other possibilities, such as purchasing additional dry lumber or purchasing some or all of the parts in the cutting bill.

Cutting Orders with Low Yields

When evaluating a cutting order, OPTIGRAMI also provides the expected percent yield of cuttings and the expected residual of 10-inch cuttings for each lumber grade in the least-cost mix and for the mix as a whole. These should be monitored closely.

Low percent yields or high amounts of short material indicate inefficient use of the raw material, which results in higher than normal costs. When this occurs, other alternatives should be considered to reduce these costs. First determine whether the low predicted yields are caused by an abnormal distribution of cutting sizes or by a small number of dimension sizes in the cutting bill; when this is determined, consider remedial alternatives.

How Can You Do Better in the Future?

By reviewing OPTIGRAMI printouts of the cutting orders for the last 3 months to 1 year, you can evaluate instances where other than optimum results were achieved. Then by recalling the prevailing circumstances, you can determine if these instances can be avoided in the future.

With OPTIGRAMI we can make management decisions regarding (1) the grades of lumber that should be purchased; (2) scheduling of lumber to be dried; (3) improving mill efficiency; (4) purchasing dimension parts; and (5) improving yields through changes in design or size requirements. Creative managers will discover additional ingenious applications for OPTIGRAMI in furniture and dimension operations.

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Acknowledgments

We greatly appreciate the cooperation of members of the faculty of the School of Forest Resources, North Carolina State University, who provided guidance and technical support during this study. We also thank USDA Forest Service employees Daniel E. Dunmire III and Edward K. Pepke for their help in demonstrating the concept's validity in industrial situations through the Rough Mill Improvement Program; and Kenneth R. Whitenack for his programing efforts.

Appendix I

Input Information Section of OPTIGRAMI Printout

July 10, 1984—COUNTRY SQUIRE SUITE—HARD MAPLE[a]

LUMBER GRADE[b]	PRODUCTION COSTS[c] (*Dollars/M bf*)	GRADE YIELD ADJUSTMENT FACTOR[d]	VOLUME CONSTRAINTS[e] (*M bf*)	LUMBER THICKNESS[f] (*Inches*)
NUMBER 2 COMMON	570.00	100.0	None	4/4
NUMBER 1 COMMON	835.00	100.0	None	4/4
FIRST AND SECONDS	1020.00	100.0	None	4/4

INPUT CUTTING ORDER

CUTTING SIZE LENGTH (*Inches*)	CUTTING SIZE WIDTH (*Inches*)	TYPE OF CUTTING RANDOM (R) OR SPECIFIED (S)	NUMBER OF CUTTINGS	NET BOARD FEET OF CUTTINGS
48.250	20.000	R	360	2412.5
30.000	19.000	R	608	2406.7
87.750	2.250	S	406	556.7
80.375	2.250	S	200	251.2
64.375	2.250	S	200	201.2
56.000	3.250	S	1850	2338.2
33.125	4.125	S	844	800.9
28.250	3.000	S	130	76.5
23.500	4.000	S	1850	1207.6
22.750	2.250	S	300	106.6
21.000	4.250	S	550	340.9
19.500	2.750	S	470	175.0
Total			7768	10873.9

[a] Cutting order identification, species, and date.
[b] Standard lumber grades chosen to be evaluated.
[c] Total production cost per M bf assigned to each grade.
[d] Adjustment made to the yield of each grade.
[e] Volume constraints imposed on each grade.
[f] Lumber thickness being considered.

Appendix II

Least-Cost Grade Mix Solution and Range and Sensitivity Analysis

Information Sections of OPTIGRAMI Printout

LEAST-COST GRADE MIX SOLUTION

July 10, 1984—COUNTRY SQUIRE SUITE—HARD MAPLE[a]

SUMMARY BY GRADE

SELECTED GRADES[b]	INPUT COST/M bf[c]	GROSS VOLUME[d]	TOTAL PRODUCTION COST[e]	BOARD FEET OF CUTTINGS[f]	PERCENT YIELD[g]
	(*Dollars*)	(*M bf*)	(*Dollars*)		
NUMBER 2 COMMON	570	7.268	4142	3541.4	48.7
NUMBER 1 COMMON	835	5.298	4424	3378.1	63.7
FIRST AND SECONDS	1020	5.855	5972	3954.5	67.5
TOTALS		18.421	14538	10873.9	59.0

RANGE AND SENSITIVITY ANALYSIS INFORMATION

SELECTED GRADES	INPUT COST AND LEVELS/M bf[h]		ASSOCIATED GROSS VOLUMES (M bf)[i]
		(*Dollars*)	
NUMBER 2 COMMON	Upper	572.59	5.785
		570.00	7.268
	Lower	559.27	7.985
NUMBER 1 COMMON	Upper	851.64	4.947
		835.00	5.298
	Lower	834.23	10.281
FIRST AND SECONDS	Upper	1021.18	2.609
		1020.00	5.855
	Lower	1009.27	6.188

[a] Identifying name or title of the cutting order, species, and date.
[b] Standard lumber grades chosen to be evaluated by OPTIGRAMI.
[c] Total production cost per M bf assigned to each grade.
[d] Quantities of each grade contained in the least-cost grade mix.
[e] Total costs for the amount of each grade of lumber used in the least-cost mix.
[f] Quantity of cuttings expected from each grade.
[g] Anticipated percent yield to be obtained from each grade.
[h] Range of input costs for each grade.
[i] Volume of that grade used in the alternate least-cost grade mix at that level of input cost.

Appendix III

Optimum Solution Cutting Information Section of OPTIGRAM! Printout

OPTIMUM SOLUTION CUTTING INFORMATION

July 10, 1984—COUNTRY SQUIRE SUITE—HARD MAPLE

SELECTED GRADES	LUMBER THICKNESS	GROSS VOLUME	CUTTING SIZE[a] LENGTH	WIDTH	TYPE OF CUTTING	NUMBER OF CUTTINGS[b]	NET BOARD FEET[c]
	(Inches)	*(M bf)*	- - - - *(Inches)* - - - -				
NUMBER 2 COMMON	4/4	7.268					
			30.000	19.000	R	608	2406.7
			28.250	3.000	S	130	76.5
			23.500	4.000	S	1117	729.2
			22.750	2.250	S	300	106.6
			21.000	4.250	S	172	106.4
			19.500	2.750	S	311	116.0
NET BOARD FEET/GRADE[d] = 3541.4							
BOARD FEET SHORTS[e] = 625.0							
NUMBER 1 COMMON		5.298					
			48.250	20.000	R	360	2412.5
			64.375	2.250	S	200	201.2
			33.125	4.125	S	202	191.8
			23.500	4.000	S	733	478.5
			21.000	4.250	S	91	56.4
			19.500	2.750	S	101	37.7
NET BOARD FEET/GRADE = 3378.1							
BOARD FEET SHORTS = 217.2							
FIRST AND SECONDS		5.855					
			87.750	2.250	S	406	556.7
			80.375	2.250	S	200	251.2
			56.000	3.250	S	1850	2338.2
			33.125	4.125	S	642	609.0
			21.000	4.250	S	287	178.1
			19.500	2.750	S	57	21.3
NET BOARD FEET/GRADE = 3954.5							
BOARD FEET SHORTS = 140.5							

TOTAL GROSS VOLUME (M bf)	TOTAL NET BOARD FEET	TOTAL SHORTS (bf)	TOTAL NUMBER OF PIECES
18.421	10873.9	982.8	7768

[a] Cuttings obtained from each grade in the least-cost solution.
[b] Expected number of each cutting to be obtained from each grade.
[c] Anticipated quantity of each cutting obtained from each grade.
[d] Total quantity of all cuttings expected from each grade.
[e] Cumulative unused net board footage of 10-inch-long cuttings available in each grade.

The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program. For cost information, please write:
Northeastern Forest Experiment Station, Forestry Sciences Laboratory, P.O. Box 152, Princeton, West Virginia 24740.

Martens, David G.; Nevel, Jr., Robert L. **OPTIGRAMI: Optimum lumber grade mix program for hardwood dimension parts.** Res. Pap. NE-563. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1985. 10 p.

With rapidly increasing lumber prices and shortages of some grades and species, the furniture industry must find ways to use its hardwood lumber resource more efficiently. A computer program called OPTIGRAMI is designed to help managers determine the best lumber to use in producing furniture parts. OPTIGRAMI determines the least-cost grade mix of lumber required to produce a given cutting order of dimension parts. If the optimum grade mix is not available, the program can determine the best alternatives. It also can be useful in procurement and allocation planning. A description of the program and examples of its use are included.

ODC 836.1

Keywords: Furniture; hardwood dimension; lumber yields; dimension yields

* U.S. GOVERNMENT PRINTING OFFICE: 1985-505-028:20025

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**Northeastern Forest
Experiment Station**

Research Paper
NE-564

1985

Component Biomass Equations for Black Spruce in Maine

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Manuscript received for publication 24 September 1984

Abstract

Component biomass prediction equations are presented for young black spruce (*Picea mariana* B.S.P. (Mill.)) in northern Maine. A weighted least squares model was used to construct the equations for small trees from 1 to 15 cm d.b.h., and an ordinary least squares model for trees less than 2 m in height. A linearized allometric model was also tested but was not used. Equations were developed for oven-dry needle, branch, bolewood, bolebark, aboveground, root, and complete tree biomass components. Aboveground components accounted for approximately 80 percent, and stump (less than 6 cm in height) plus roots accounted for 20 percent of the complete tree oven-dry biomass accumulation.

Introduction

Black spruce (*Picea mariana* B.S.P. (Mill.)) is a geographically wide-ranging species that occurs on 76,000 hectares in the State of Maine alone (Ferguson and Kingsley 1972). High fiber quality, ability to grow on poor sites, and apparent resistance to spruce budworm (*Choristoneura fumiferana* (Clem.)) defoliation make black spruce an increasingly valuable fiber resource. The development of whole-tree harvesting and utilization technologies, to make more efficient use of wood crops, has created a need for reliable estimates of tree biomass. Equations relating individual tree diameter and height to component biomass dry weight have been developed by Young *et al.* (1964, 1980) for mixed species of spruce in Maine. Other equations have been published for black spruce in Minnesota (Schlaegel 1975) and in Canada (Alemdag 1982, Freedman *et al.* 1982, Ker 1980, 1984, Moore and Verspoor 1973, Ouellet 1983).

The objective of this study was to develop component biomass prediction equations for naturally regenerated, unmanaged, poor-site black spruce in Maine. The equations were constructed to relate component biomass dry weight to diameter outside bark at breast height and diameter outside bark at 15 cm above ground line.

Study Area

The study was conducted immediately north of Square Lake (latitude 47°06″, longitude 68°23″) in T-16 R-5 Aroostook County, Maine. The climate is characterized as humid, cool, continental (Arno 1964) with a mean yearly temperature of 3.6°C. Annual temperature extremes range from a mean low of −11.9°C in January to 18.0°C in July. A frost-free season of 107 days (May 30 to September 16) is typical. Average annual precipitation in the area is 92 cm (Ruffner 1978).

The soils are relatively uniform, consisting of poorly and very poorly drained complexes formed in lake-laid lacustrine deposits and are overlain by varying depths of organic materials, mostly of *Sphagnum* spp. origin. The microtopography is an intricate association of hummock and hollow relief. Overall, the area (1200 ha) is level and is situated 6 m above the surface of Square Lake at an elevation of 183 m.

The black spruce stand (98 percent pure) occupying the site developed following clearcutting in 1957. The stand is even-aged, but the age of individual trees varies by as much as 20 years due to advanced regeneration, layering, and ingrowth. A wide range of diameters and heights (1 to 11 cm and 1 to 8.5 m, respectively) results in an uneven canopy surface. Density of stems greater than 0.5 m in height is as high as 14,000 per hectare, and open areas as large as 4.5 m in diameter occur occasionally.

Methods

Field and Laboratory Procedures

A total of 39 trees from 1 to 15 cm d.b.h. was randomly selected to represent the range of diameters present. Root systems were excavated from 20 of these 39 trees. To account for small trees, an additional 25 trees with diameters from 1 to 3 cm at 15 cm above ground were sampled. Trees with broken tops and distorted or forked boles were excluded from the sample. Sample trees came from unmanaged areas, except for the largest trees which were located adjacent to drainage ditches. In these areas, stand development was enhanced and larger trees were available for sampling.

Sample trees were measured at breast height to the nearest 0.1 cm, cut to within 6 cm of the ground, and total tree height measured to the closest 0.01 m. Dead branches and live crown were cut from the trees and weighed separately in the

field (± 0.01 kg). To account for moisture content changes within the crown and to accommodate the maximum capacity of the field scale, crowns of the largest trees were cut and weighed in three sections, those of moderate size trees in two sections, and the crowns of the smallest trees were weighed as a single unit. A whorl of branches was removed from the center of each live-crown section and from the area of dead crown for moisture content and percent foliage determination.

Sampled whorls were sealed in double plastic bags and transported to the laboratory where fresh weight (± 0.1 g) was recorded within 36 hours. Branch samples with needles were oven-dried at 65°C to constant weight and percent moisture computed. Moisture content data were applied to the fresh weight of each crown section and summed to obtain the dry weight of the entire crown. Needles were separated from live-crown sample whorls and weighed to determine the percent needle component. This ratio was used to calculate needle and branch dry weight for each crown section and then summed for the whole crown.

Boles were cut into 1.22-m bolts and weighed (± 0.1 kg) in the field. A disk (4 to 7 cm thick) was cut from the base of each bolt, placed in a double plastic bag, and transported to the laboratory. Bark, including cambium, was separated from the wood of each disk and fresh weight (± 0.1 g) of bark and wood recorded separately within 36 hours. Wood and bark were oven-dried at 65°C to constant weight and percent moisture was calculated. The dry weights of bark and wood were calculated for each bolt and summed for the entire bole.

These procedures were followed for all aboveground sampling except for the smallest trees sampled. In these instances, the entire tree, by component, was transported to the laboratory for both fresh and oven-dry weight determination.

Root systems were confined almost entirely to the surface organic soil with only a few small roots extending into the subsurface mineral soil. The area of an individual tree root system was estimated as similar in size to the area of the trees live crown projected onto the ground around its base. From within this defined area, stump and roots were excavated. Roots which extended beyond the estimated area were traced and removed, as well as possible. The extracted root systems were cleaned of soil, cut into manageable pieces, bagged, and taken to the laboratory. Roots were then carefully cleaned, weighed, oven-dried at 65°C, and oven-dry weight recorded (± 0.1 g). Small roots and fine rootlets lost in the excavation were not accounted for and are not included in the biomass estimates.

Statistical Procedures

For trees from 1 to 15 cm d.b.h., the diameter outside bark at breast height was chosen as the independent variable for the biomass prediction equations as this variable has been shown to be strongly correlated with individual tree biomass and is an easily obtained inventory measurement. Graphical analysis of the sample data substantiated that the relationship between component biomass and d.b.h. was curvilinear and that the variation in component biomass increased with increasing diameter. Two models were tested to fit the data:

(I) weighted least squares

$$y = B_1 + B_2 \cdot d + B_3 \cdot d^2 + e$$
$$e \sim N(0, d^4, \sigma^2)$$

(II) linearized allometric

$$\ln(y) = \ln(B_1) + B_2 \cdot \ln(d) + \ln(e)$$
$$\ln(e) \sim N(0, \sigma^2)$$

where y = component biomass dry weight (kg)
d = d.b.h. (cm) and
B_1, B_2, and B_3 are unknown parameters.

Graphs of the conditional variance of component biomass by diameter class verified that the variances were proportional to the 4th power of diameter. Furnival's Index (1961) was used to determine whether model I or II best fit the data.

Graphical analysis of sample data for trees with diameters from 1 to 3 cm at 15 cm above ground showed that the relationship between biomass and tree diameter at 15 cm was linear and that the conditional variance of component biomass was homogeneous. The ordinary least squares method was used to fit the following linear model for these trees:

$$y = B_1 + B_2 \cdot d + e \qquad e \sim N(0, \sigma^2)$$

where y = component biomass dry weight (kg)

d = diameter (cm) at 15 cm and

B_1 and B_2 are unknown parameters.

Results and Discussion

Sample-tree mensurational and component biomass data are summarized in Table 1. Complete sample-tree dry weight ranged from 0.1 to 85.4 kg and above ground weights from 0.1 to 69.1 kg.

Model I was selected to construct the prediction equations for trees 1 to 15 cm d.b.h. Although neither model, based upon Furnival's Index (1961), consistently provided better results (Table 2), the weighted least squares model has advantages which favor its selection. This model facilitates the calculation of unbiased biomass prediction and confidence limits (Fig. 1). In addition, the model provided a statistically better fit to the data for bolewood and bolebark, the tree components most commonly utilized. The model also provided a better fit for root and complete tree biomass than did the linearized allometric model. Several other researchers have supported use of the weighted least squares model in the construction of biomass equations (Crow and Laidley 1980, Cunia 1979, Schreuder and Swank 1973).

Table 1.—Black spruce sample tree mensurational data and mean biomass by component (kg)

Sample tree size class d.b.h. (cm)	Range of sample d.b.h.	Range of sampled height	Needle	Branch	Bolewood	Bolebark	Above-ground	n	Stump & root	Complete tree	n
	cm	*m*			*kg*					*kg*	
1	0.9- 1.1	1.7- 1.8	0.24	0.17	0.23	0.06	0.72	5	0.25	0.95	1
3	2.0- 3.1	2.9- 3.8	.60	.47	.78	.20	2.05	5	.44	2.44	4
5	5.0- 5.3	4.6- 6.2	1.13	1.13	2.46	.52	5.24	6	1.22	6.13	4
7	6.9- 7.0	6.5- 7.8	2.01	1.80	5.43	1.01	10.25	5	2.23	12.88	2
9	8.9- 9.1	7.7- 9.0	3.46	3.49	10.36	1.62	18.95	5	4.68	23.53	4
11	10.9-11.1	9.6-10.6	4.54	5.79	19.15	3.08	32.56	5	9.94	43.22	2
13	12.8-13.4	8.8-11.7	8.36	10.83	26.40	3.83	49.42	5	14.36	62.74	2
15	14.8-15.2	10.0-12.1	9.60	16.70	37.56	5.30	69.14	3	18.13	85.45	1
Diameter at 15 cm (cm)	Diameter range	Range of sampled height	Needle	Branch	Bolewood	Bolebark	Above-ground	n	Stump & root	Complete tree	n
	cm	*m*			*kg*					*kg*	
1.0	0.9-1.2	0.74-1.05	0.031	0.026	0.027	0.010	0.093	—	0.034	0.127	7
1.5	1.3-1.7	.69-1.19	.054	.049	.042	.015	.160	—	.046	.206	9
2.0	1.8-2.4	1.24-1.63	.191	.154	.122	.037	.503	—	.141	.644	6
3.0	2.5-3.5	1.86-1.93	.261	.262	.224	.072	.820	—	.205	1.025	3

Table 2.—Comparison of the fit of weighted least squares and linearized allometric models to component biomass data using Furnival's Index[a]

Component	Model	
	Weighted least[b] squares	Linearized[c] allometric
Needle	1.82	0.74
Branch	1.20	.85
Bolewood	.81	1.50
Bolebark	.15	.33
Aboveground	3.44	2.41
Stump and root	.58	1.05
Complete Tree	1.55	3.33

[a] The smaller value of Furnival's Index, the better the model fits.

[b] $y = B_1 + B_2 \cdot d + B_3 \cdot d^2 + e$ $\quad e \sim N(0, d^4\sigma^2)$

[c] $\ln(y) = \ln(B_1) + B_2 \cdot \ln(d) + \ln(e)$ $\quad \ln(e) \sim N(0, \sigma^2)$

Coefficients for the weighted least squares regression of component biomass on d.b.h. are given in Table 3 for trees from 1 to 15 cm d.b.h.[1] The coefficients of determination for complete tree, aboveground, bolewood, bolebark, and root and stump biomass are high (0.98, 0.83, 0.96, 0.95, and 0.93, respectively) while those for branch and needle components are lower (0.62 and 0.32, respectively). These differences reflect the complexity of the stand canopy and thus a high degree of variation in crown components. These factors were not considered in sample tree selection.

Prediction equations for small trees, diameter measured at 15 cm, are presented in Table 4. Height of these small trees was also considered as an independent variable in equation construction. However, it did not prove to be a good predictor of biomass. It is important to measure small trees because they can be a significant portion of stand biomass. In some of the stands sampled, there were more than 62,000 stems per hectare of these small trees.

[1] Confidence and prediction limit for oven-dry biomass components are available upon request from the senior author.

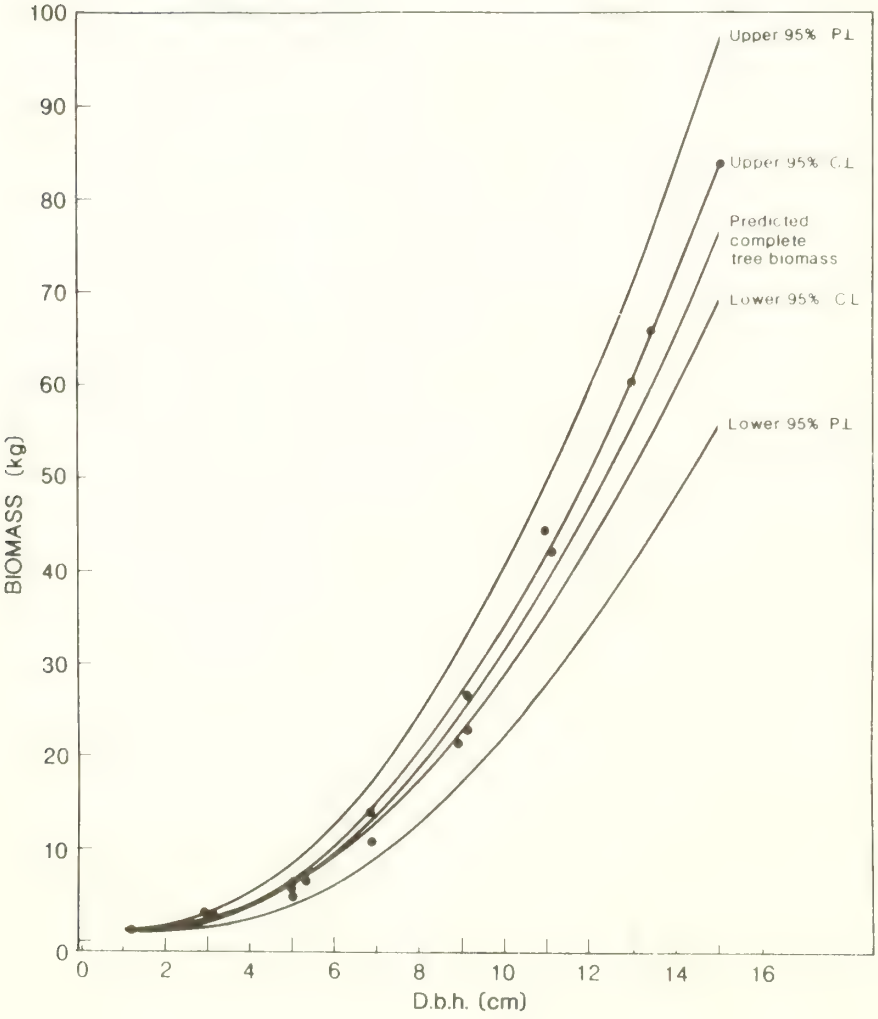

Figure 1.—Relationship of black spruce complete tree biomass and d.b.h. with 95 percent confidence limits (95% C.L.) and 95 percent prediction limits (95% P.L.).

Table 3.—Coefficients for the weighted least squares regressions of component biomass for black spruce trees on d.b.h., from 1 to 15 cm.

Component	Coefficients[a]					
	b_0	b_1	b_2	r^2	s^{2b}	n
Needle	0.29	− 0.0799	0.04894	0.32	0.00291	39
Branch	.25	− .1378	.06293	.62	.00120	39
Bolewood	.49	− .4480	.17931	.96	.00056	39
Bolebark	.07	− .0284	.02429	.95	.00002	39
Aboveground	1.09	− .6941	.31546	.83	.01019	39
Stump and root	.48	− .3117	.09359	.93	.00024	20
Complete tree	1.50	− .9325	.39532	.98	.00168	20

[a] The model is: $y = b_0 + b_1 d + b_2 d^2$
where y = component biomass (kg)
d = diameter outside bark at breast height (cm)
[b] $S^2 y \cdot x = d^4 s^2$

Table 4.—Coefficients for the ordinary least squares regression of component biomass of black spruce trees on diameter, from 1 to 3 cm, at 15 cm.

Component	Coefficients[a]				
	b_0	b_1	r^2	$s^2 y \cdot x$	n
Needle	− 0.1627	0.1583	0.86	0.00143	25
Branch	− .1655	.1530	.88	.00114	25
Bolewood	− .1231	.1194	.93	.00037	25
Bolebark	− .0356	.0362	.94	.00003	25
Aboveground	− .4869	.4669	.92	.00700	25
Stump and root	− .1231	.1227	.87	.00082	25
Complete tree	− .6100	.5397	.92	.01149	25

[a] The model is: $y = b_0 + b_1 d$
where y = component oven-dry biomass (kg)
d = diameter outside bark at 15 cm (cm)

Oven-dry biomass distribution by component indicates that approximately 80 percent of complete tree biomass is accumulated aboveground and approximately 20 percent in the stump and roots. Bolewood accounts for the largest proportion of complete tree biomass (40 percent) and bolebark the least (7 percent).

Oven-dry component biomass distribution as a percentage of total tree biomass changes with tree size (Fig. 2). The percentage of complete tree biomass in needles, branches, bolebark, and aboveground components decreases (from 19 to 12, 17 to 15, 8 to 6, and 82 to 79 percent, respectively) from size class 1 to 7 cm d.b.h., to size class 9 to 15 cm d.b.h. Bolewood and root biomass increase (from 37 to 44 and 19 to 21 percent, respectively) for the same two size classes. Similar biomass distributions have been reported for black spruce by Freedman and others (1982) and Ker (1984).

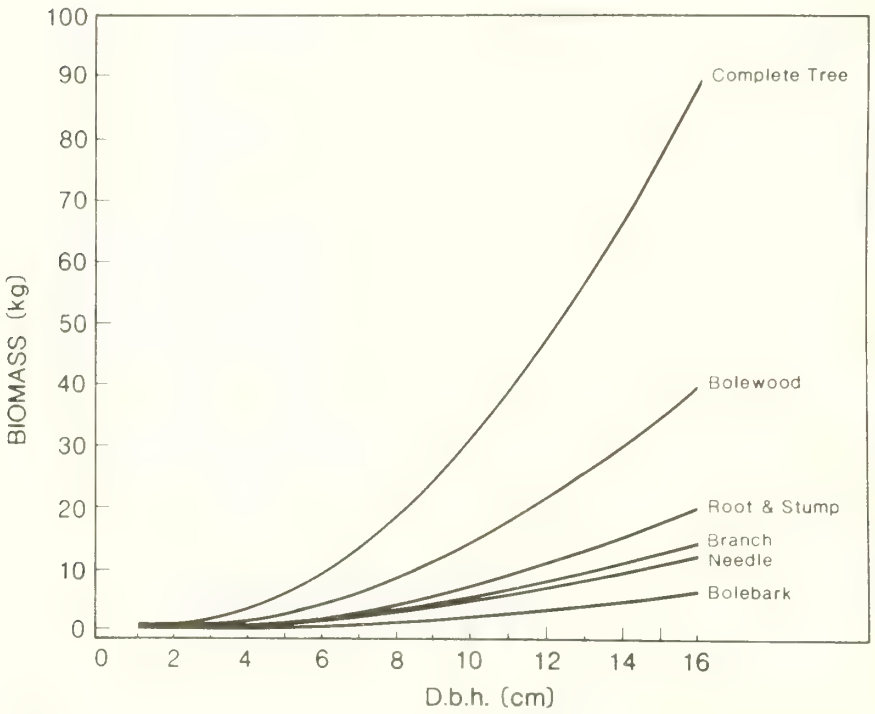

Figure 2.—Relationship of black spruce component biomass and d.b.h. as predicted by regression equations.

Acknowledgment

The authors gratefully acknowledge the assistance of Dr. L. P. Abrahamson in the preparation of this manuscript.

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Czapowskyj, M. M.; Robison, D. J.; Briggs, R. D.; White, E. H. **Component biomass equations for black spruce in Maine.** Res. Pap. NE-564. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1985. 7 p.

Component biomass prediction equations are presented for young black spruce (*Picea mariana* B.S.P. (Mill.)) in northern Maine. A weighted least squares model was used to construct the equations for small trees from 1 to 15 cm d.b.h., and an ordinary least squares model for trees less than 2 m in height. A linearized allometric model was also tested but was not used. Equations were developed for oven-dry needle, branch, bolewood, bolebark, aboveground, root, and complete tree biomass components. Aboveground components accounted for approximately 80 percent, and stump (less than 6 cm in height) plus roots accounted for 20 percent of the complete tree oven-dry biomass accumulation.

Keywords: Black spruce, biomass distribution

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**Northeastern Forest
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Research Paper
NE-565

1985

The Cost of Maple Sugaring in Vermont

Paul E. Sendak
John P. Bennink

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Manuscript received for publication 15 October 1984.

Abstract

We developed an annual maple-syrup-production cost series for the period 1972 to 1984. We specified the physical input required for a 3,000-tap, plastic tubing with vacuum system with an oil-fired open-pan evaporator. Current value data were used to estimate the annual production cost of a gallon of syrup. Cost increased from 6.16 per gallon in 1972 to $15.93 in 1984; however, much of this increase is the result of inflation. The sugarhouse, where syrup is processed, accounted for a relatively larger share of the total cost of production in 1984 (66 percent) than it did in 1972 (53 percent). A sensitivity analysis indicated that total cost is most sensitive to changes in wages for labor and cost of fuel oil.

Introduction

What does it cost to make a gallon of maple syrup? This question was answered for a few points in time. However, an annual series of syrup production cost had never been developed so that the trend in cost could be studied. Such a series could be used to examine the effects of changing technology and the relationships between major cost areas, such as sap collection and syrup processing, over time. It could be used to assess the potential benefits of new technology by equipment developers, manufacturers, and syrup producers. Financial analyses by syrup producers and lenders supplying capital to the industry could be done more accurately using information from a production cost series. Public policy analysts and planners could use the information to improve their understanding of the industry.

Our objectives were to develop time series of maple production costs and to observe the effects of changing technology, fuel price, interest rate, and sap sugar content on production cost. In addition, the relationships between major production cost items were examined.

The USDA Forest Service reported costs of maple sap production for 1972 to 1973 and the cost of maple syrup production for 1977 (Huyler 1975, Huyler and Garrett 1979). That information was updated in 1980 (Huyler 1982a, Huyler 1982b). These studies specified the relationships between physical inputs, such as labor and equipment, and syrup production.

The production cost index was based on cost data estimated for a 3,000-tap tubing with vacuum operation and an oil-fired evaporator. Cost increased steadily from 1972 through 1981. From 1982 through 1984, the last year in the series, the index stabilized. Costs increased more than 2.5 times from 1972 ($6.16 per gallon) to 1984 ($15.93 per gallon). The farm price for maple syrup almost doubled over the same period, from $9.30 to $17.20 per gallon.

Methods

Obtaining actual costs of maple syrup production even for a small sample of maple syrup operations is difficult. Moreover, unless collected on an annual basis, annual costs are difficult to reconstruct. The highly variable nature of the industry in terms of syrup yield per tap, sugarbush size and layout, and sap collection and syrup processing techniques makes analysis of these data potentially difficult.

An alternative method is to: (1) specify the equipment necessary to produce maple syrup for a commercial size operation; (2) define the relationship between physical inputs of production, such as labor and fuel, and physical outputs, such as sap and syrup; and (3) convert physical units to dollars by applying annual estimates of prices or values of items for which no money need be exchanged, such as volunteer labor.

Huyler (1975) has shown that the tubing with vacuum system is the lowest cost method of sap collection. We chose this system for our production cost trend analysis. For comparison, production costs for the traditional bucket system were also estimated.

Syrup processing in a conventional open-pan evaporator is standard for the industry. The two major fuels are wood and No. 2 fuel oil but natural gas and LP gas are sometimes used. No. 2 fuel oil was compared to wood because price information for these fuels is readily available.

A 3,000-tap operation was selected for analysis. Huyler and Garrett (1979) have shown that this size is large enough to achieve most of the cost economies of larger operations in both average investment and annual operating costs. It is large enough to make a significant contribution to the owner's total income, but not so large as to be more than a supplemental source of income, the typical situation in the maple syrup industry. For comparison, production costs for 2,000- and 4,000-tap operations were also estimated.

Figure 1 shows the process we used to create the maple syrup production cost index. The Appendix contains tables that include standard equipment lists; labor and energy requirements; and sources for property tax, insurance, and price information.

Two factors not considered in the analysis were appreciation of land value accruing to the landowner and income tax. The addition of both items would add unnecessary complexity to the analysis without much benefit. Widely varying land values, due to factors largely external to maple syrup production, would make a statewide average difficult to obtain and questionable.

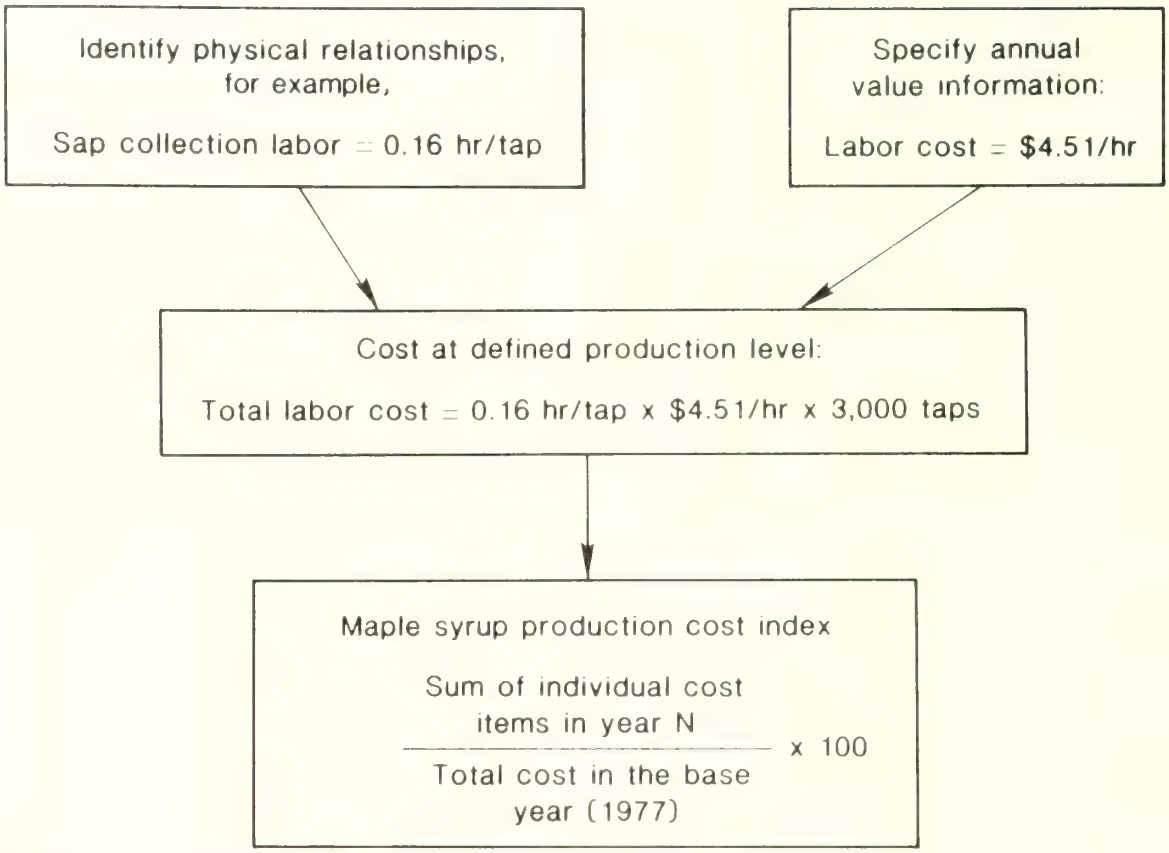

Identify physical relationships, for example,
Sap collection labor = 0.16 hr/tap
Specify annual value information:
Labor cost = $4.51/hr
Cost at defined production level:
Total labor cost = 0.16 hr/tap x $4.51/hr x 3,000 taps
Maple syrup production cost index
Sum of individual cost items in year N
Total cost in the base year (1977)
x 100

Figure 1.—Schematic of the method used to calculate the maple syrup production cost index.

Results

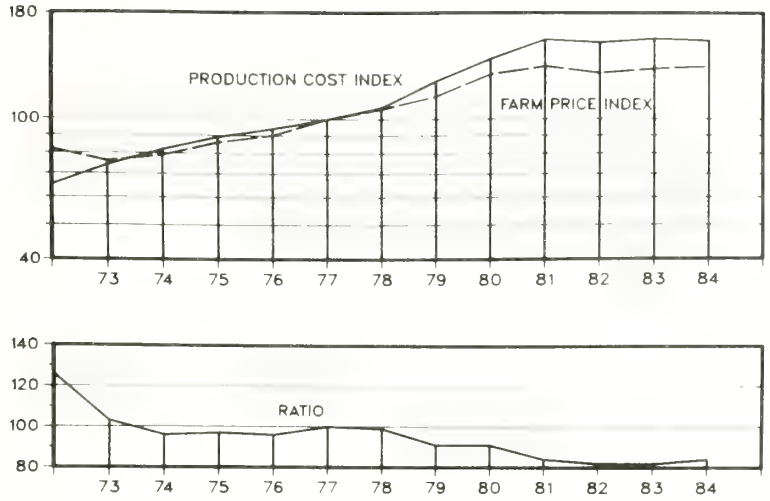
Production Cost Index

Figure 2 shows the annual production cost per gallon of syrup expressed as an index (1977 = 100) for the period 1972 to 1984. This index includes the value of input factors for each year including equipment and building depreciation based on current cost. The cost data were estimated for a 3,000-tap tubing with vacuum operation and an oil-fired evaporator.

Cost increased steadily over the period until 1982, when the index began to stabilize. Major increases in cost occurred in 1979, 1980, and 1981. Cost increased more than 2.5 times from 1972 ($6.16 per gallon) to 1984 ($15.93 per gallon). Much of the increase in cost was inflationary.

The trend in annual maple syrup price is also shown as an index (1977 = 100) in Figure 2. This index is based on price reported by the Statistical Crop Reporting Service for Vermont which is an average price received at the farm for all sales including retail and wholesale (USDA, Stat. Rep. Serv. 1972-84). In 1972, the exceptionally high price was most likely the result of below average production in both the U.S. and Canada in 1971 leading to a world shortage of maple syrup. After 1973, the trend in price was steadily upward until 1982. In 1982, the decline in maple price was most likely the result of above average production in both the U.S. and Canada leading to a world surplus of maple syrup. Price almost doubled from 1973 ($9.30 per gallon) to 1984 ($17.20 per gallon).

Figure 2 also shows the ratio of the maple syrup price index and the production cost index. A value of 100 indicates that the two indexes were equal, that is, prices and production costs changed in the same proportion relative to their



YEAR	COST OF MAPLE SYRUP PRODUCTION	MAPLE SYRUP PRICES RECEIVED BY PRODUCERS	RATIO[a]
	INDEX		
1972	65	82	126
1973	74	76	103
1974	82	79	96
1975	89	86	97
1976	94	90	96
1977	100	100	100
1978	108	107	99
1979	128	116	91
1980	148	134	91
1981	168	141	84
1982	165	135	82
1983	169[b]	139[b]	82[b]
1984	167[b]	141[b]	84[b]

[a] RATIO OF INDEX OF MAPLE SYRUP PRICES RECEIVED BY PRODUCERS TO INDEX OF COST OF MAPLE SYRUP PRODUCTION

[b] PRELIMINARY ESTIMATE

Figure 2.—Production cost index for maple syrup, maple syrup price index, and ratio of price index to cost index.

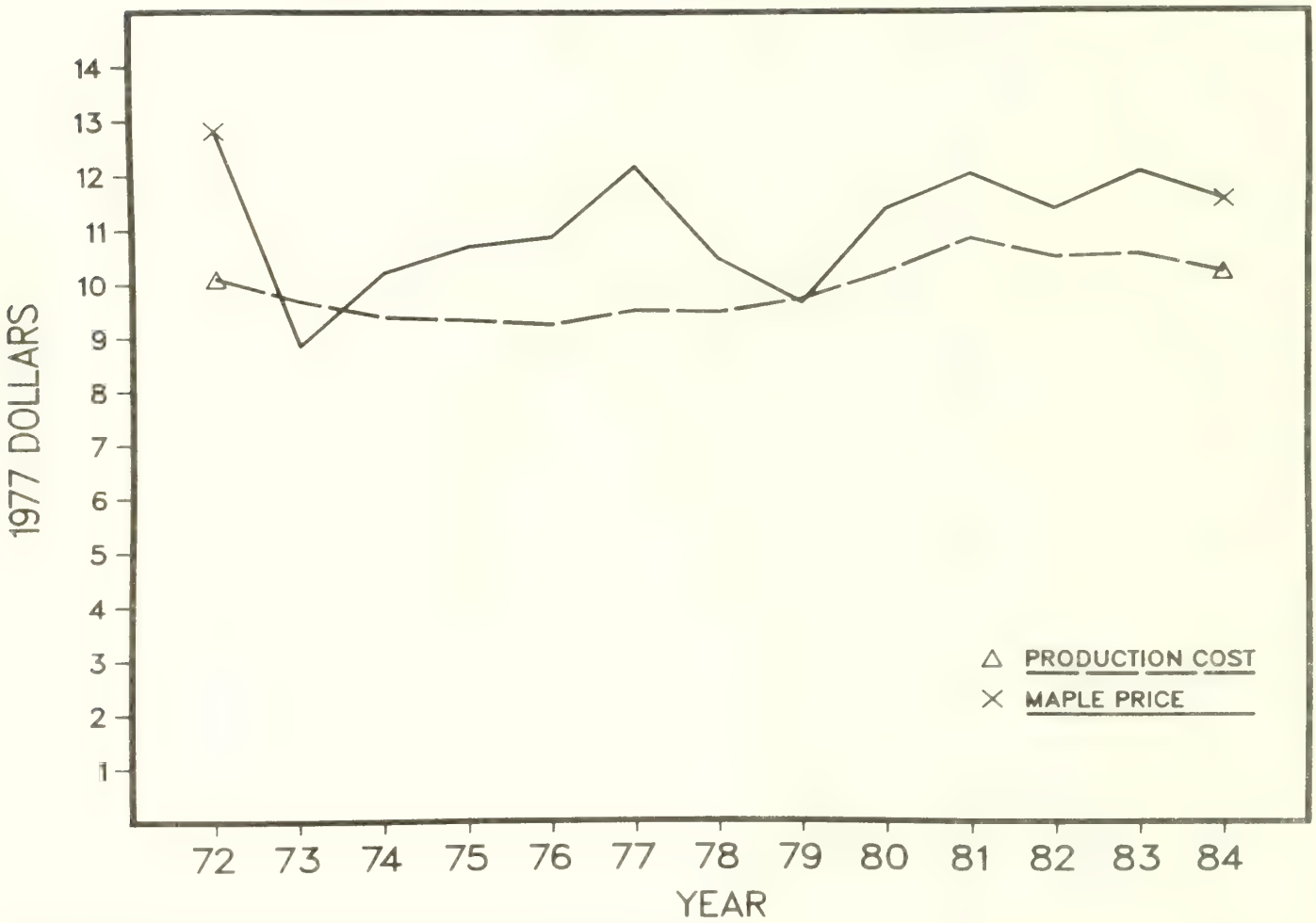


Figure 3.—Product cost and farm price for maple syrup in Vermont in constant (1977) dollars, 1972-84.

respective base year value. The ratio for most years is near 100. However, in 1972, the maple price index was significantly higher than the production cost index yielding a ratio of 126. In 1982 and 1983, the reverse in the upward maple price index trend is reflected in values significantly lower than the production cost index yielding a ratio of 82 for both years. Perhaps this reflects an adjustment toward equilibrium between supply and demand in the maple syrup market after a major change in quantity of syrup produced.

The study period included the worst period of inflation in modern U.S. history. The year to year change in the Consumer Price Index (CPI) exceeded 10 percent for 1979, 1980, and 1981. Only in 2 other years since World War II did the year to year change in the index exceed 10 percent. The change exceeded 5 percent in 16 of the last 39 years (Council of Economic Advisers 1984). To remove the effect of inflation, production costs were adjusted by the Index of prices paid by farmers for production items. Maple syrup prices were adjusted by the Index of prices received by farmers for livestock and products (Council of Economic Advisers, 1972-84).[1] Figure 3 shows the maple production cost and syrup price series in 1977 (constant value) dollars. Measured in constant value dollars, production costs have varied little over the period—only 17 percent from the lowest cost, $9.26 (1976), to the highest, $10.84 (1981). Maple syrup prices showed greater fluctuation over the period—about 45 percent from the lowest price, $8.86 (1973), to the highest, $12.82 (1972). The production cost weighted by annual syrup production averaged $9.97 (1977 dollars) per gallon over the period and weighted syrup prices averaged $11.16 per gallon.

[1] The annual syrup production cost or syrup price was divided by the appropriate index number and the quotient multiplied by 100 to obtain the adjusted cost or price.

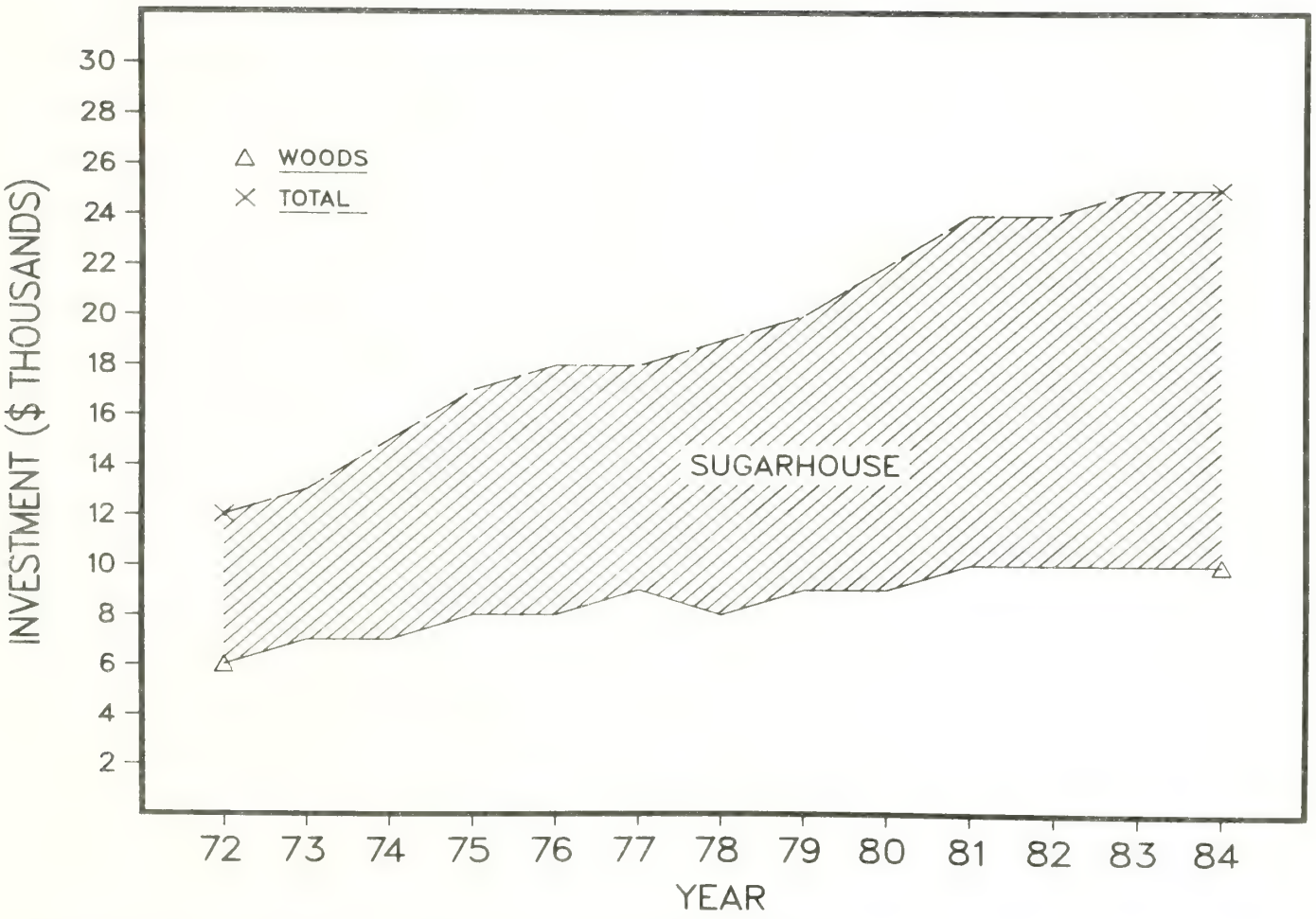


Figure 4.—Investment in sap collection equipment and syrup processing equipment and building for a 3,000-tap operation: tubing with vacuum, with an oil-fired evaporator, 1972–84.

Comparative Analyses

Investment versus annual operating cost. Investment is the money needed to purchase the equipment and building for the production of maple sap and syrup and is linked to annual operating cost through calculation of an annual equivalent of investment.[2] Annual equivalent provides for both repayment of the investment and a return on the investment for the life of the building or equipment (Smith 1968). Annual operating cost is incurred each year in the production operation and includes cash items, such as fuel and wages, and non-cash items, such as annual equivalent of investment in equipment and the opportunity cost of the operator's time. The annual operating cost is the same as production cost presented in Figure 2.

Investment can be separated into the woods or sap collection activity and the sugarhouse or syrup processing activity (Fig. 4). Investment in both woods and sugarhouse increased steadily since 1972 but leveled off in 1983 and 1984. During this period, investment doubled from $12,500 in 1972 to $25,000 in 1984 (3,000 taps, tubing with vacuum, and oil-fired). Investment increased more rapidly for syrup processing than for sap collection. In 1972, sap collection was about 50 percent of total investment and only 40 percent in 1984.

[2] $A = B\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$

where A = annual equivalent of investment,
B = investment,
i = interest rate,
and n = life of building or equipment.

Note: Salvage value is assumed to be zero.

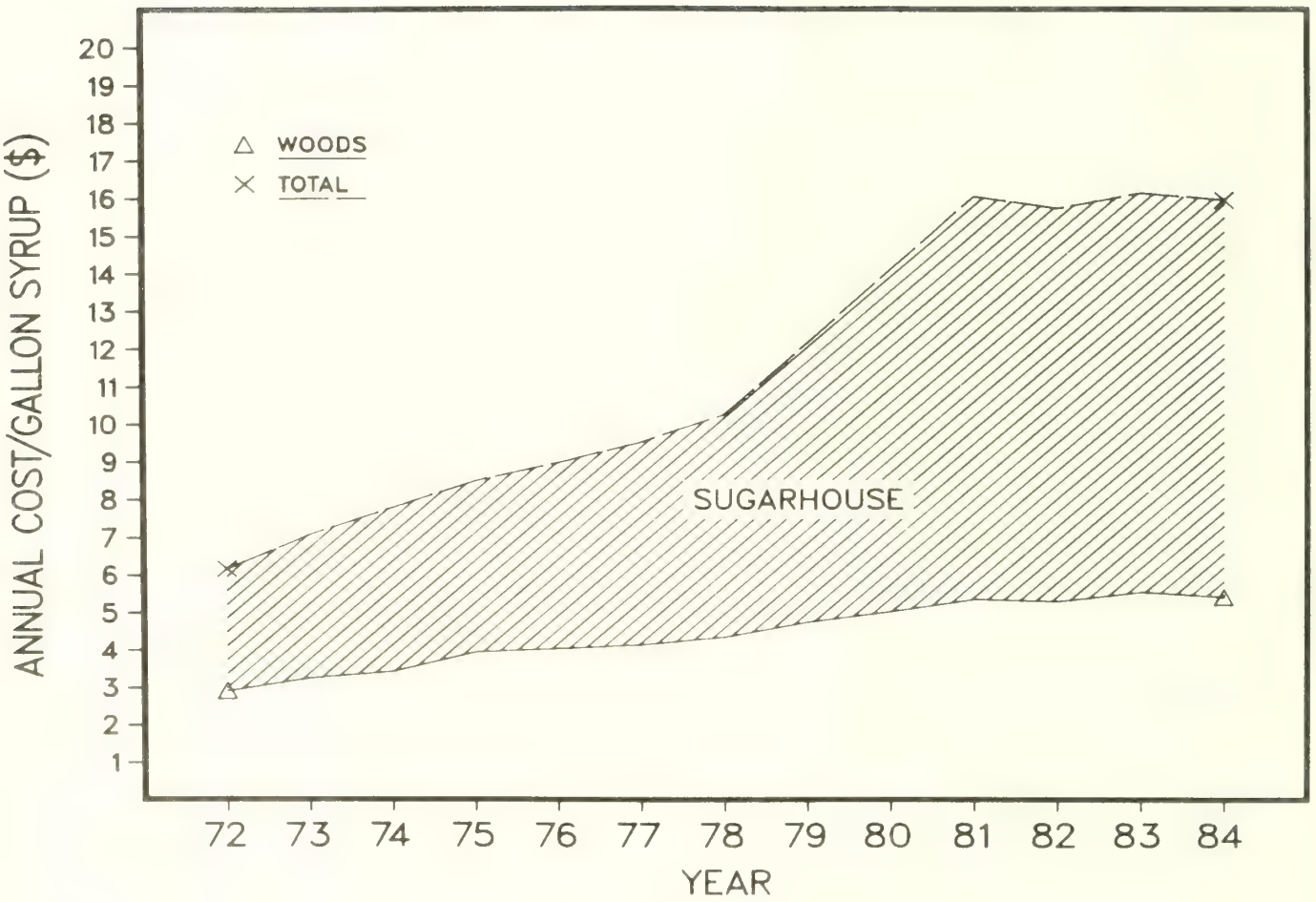


Figure 5.—Production cost per gallon of syrup for sap collection and syrup processing activities, 1972–84.

Woods versus sugarhouse: annual operating cost. The sap collection (woods) and syrup processing (sugarhouse) activities changed at different rates for annual operating cost as well as investment cost (Fig. 5). In 1972, the woods activities accounted for 47 percent of the total syrup production cost compared to 34 percent in 1984. The higher investment for syrup processing and the increase in fuel oil price account for most of the increase.

Changing technology: tubing versus buckets. Collecting sap in galvanized iron buckets was standard in the industry for many years. In the 1950's plastic tubing was introduced. After several years of trials and experimentation, a superior technique was developed—the closed dropline aerial system with vacuum pumping (Walters 1982).

Advantages of tubing over bucket systems are reflected in cost of operation. Huyler (1975) estimates that a tubing system requires 22 percent less labor time than a bucket system and yields 28 percent more sap per tap. In addition, tubing systems require a lower capital investment per tap than buckets. In 1972, the annual operating cost per gallon of syrup was $7.56 for buckets and $6.16 for tubing. In 1984, it was $21.33 for buckets and $15.93 for tubing (Fig. 6). The cost gap between the two systems has steadily widened. In 1972, tubing represented 81 percent of the annual cost per gallon for buckets; in 1984 it was 75 percent.

Fuel choice: wood versus oil. In the 1950's, fuel oil began to replace wood as an evaporator fuel because it was cheap, clean, and

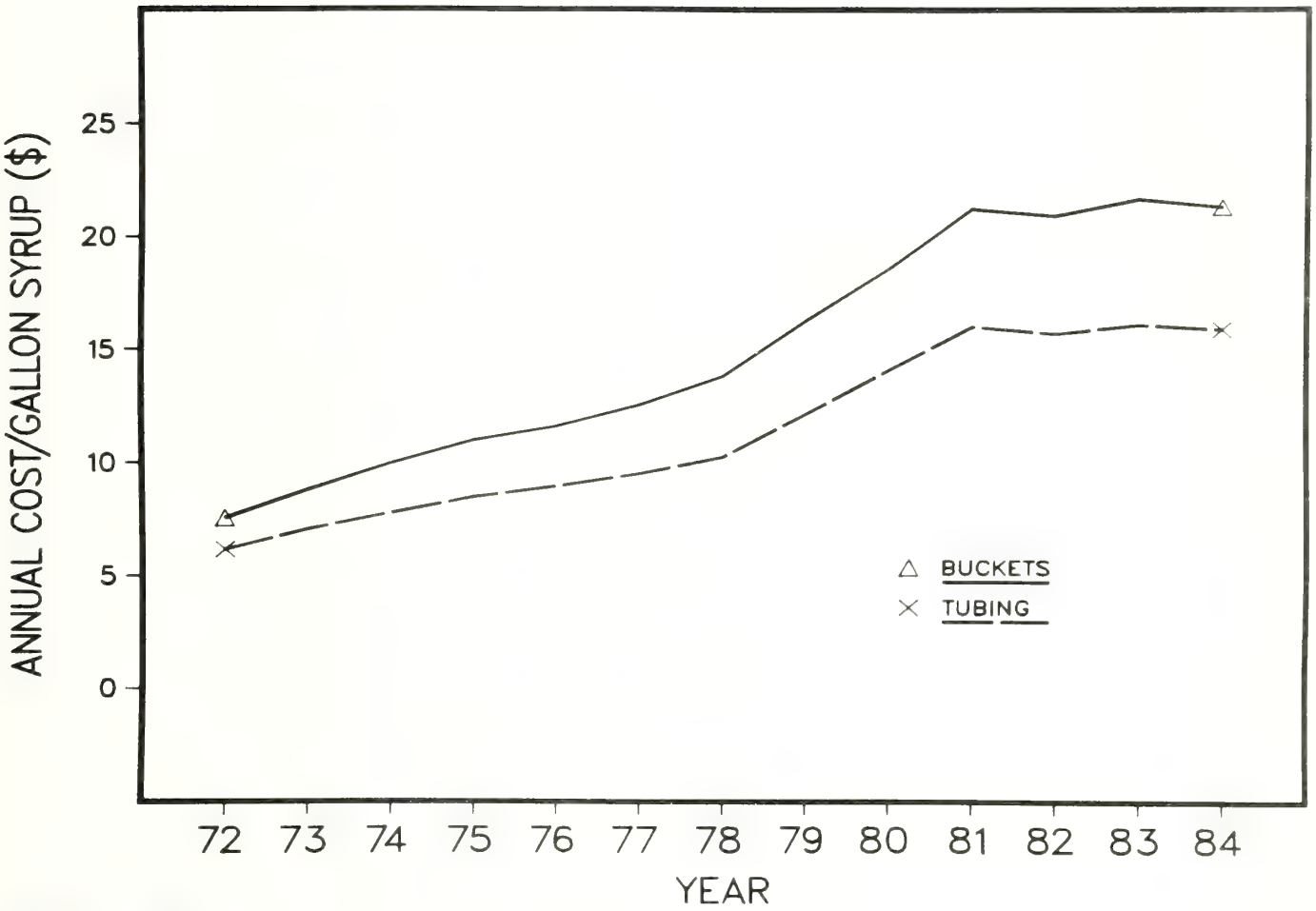


Figure 6.—Production cost per gallon of syrup for tubing with vacuum operation compared to a bucket operation, 1972–84.

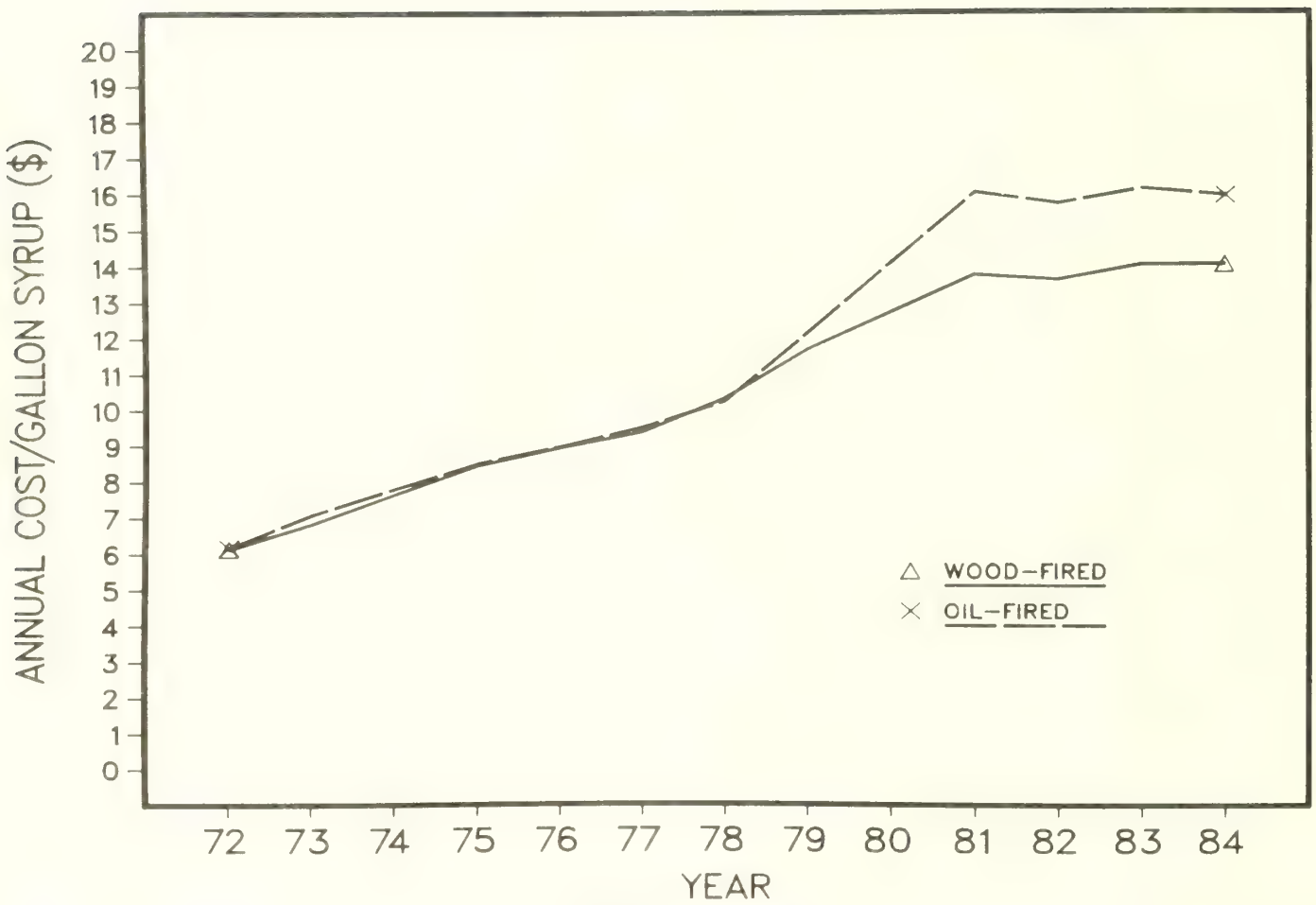


Figure 7.—Production cost per gallon of syrup for an oil-fired operation compared to a wood-fired operation, 1972-84.

more efficient. During the 1970's, oil had increased in price to such a level that its impact on syrup production cost overwhelmed its convenience value and other advantages. From 1972 to 1984, the price of No. 2 fuel oil rose from $.30 to $1.24 per gallon. Figure 7 shows how rising oil prices affected the annual cost of producing syrup. In 1972 through 1978, the two fuels yielded comparable production costs. However, in 1979 this changed and by 1984 wood-fueled production cost was 12 percent lower than oil-fueled.

Sap Sugar

Natural variability among individual trees and environmental factors influence sap-sugar content and flow (Gabriel 1982, Gregory 1982). Gabriel (1972) reported a range in sap-sugar content of from 0.7 to 10.8 percent for 21,080 trees in the Northeast. A widely accepted average for commercial sugarbushes in Vermont is 2.5 percent sugar content and a yield of 10 gallons of sap per tap. A base of 2.15 percent sugar and a yield of 10 gallons was used for calculating production costs per gallon of syrup for a bucket operation.

Production costs vary with sugar content because of changes in the amount of water removed per gallon of syrup. For example, 100 gallons of 2 percent sap will yield 2-1/3 gallons of syrup, while the same amount of 4 percent sap will yield 4-2/3 gallons of syrup, or twice the syrup for about the same total processing cost.

Figure 8 shows how production costs per gallon of syrup change with changing sugar content. A 100 percent change in sugar content from 1.5 percent to 3.0 percent resulted in a 40 percent decrease in production cost from $20.98 per gallon of syrup to $12.64.

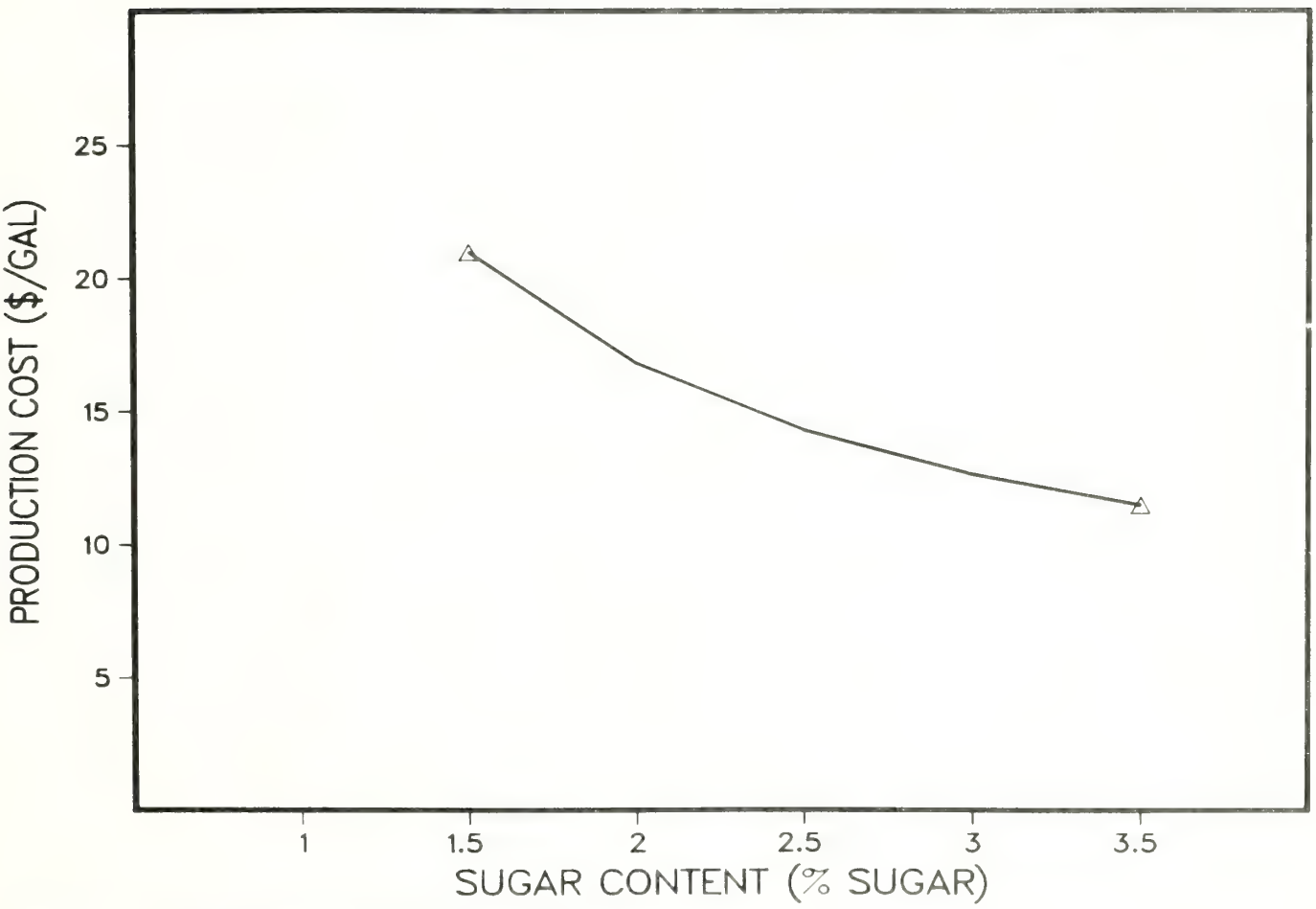


Figure 8.—Production cost per gallon of syrup related to average sugar content of sap.

Scale Effects of Economies of Size

Scale effects in maple sugaring can be attributed to more efficient use of equipment with increasing size. For example, items such as tools, tree power-tapper, vacuum pump system, and many items in the sugarhouse are needed for all operations regardless of size. They are fixed costs with respect to the operation. However, when averaged over more taps and gallons of syrup in larger operations, they decrease on a per tap or per gallon basis. In 1984, production costs per gallon were $17.64, $15.93, and $15.14 for a 2,000-, 3,000-, and 4,000-tap operation, respectively.

Sensitivity Analysis

Total production cost is a summation of the individual cost items. Over time, the items change in price or value in absolute terms and relative to each other. Small changes in major cost items can have a greater impact on the total than large changes in minor cost items. The sensitivity of total production cost in 1984 to individual changes in the major cost items was tested.

Change in fuel oil and labor costs resulted in the largest change in total production cost per gallon of syrup (Table 1). An increase of 50 percent in the cost of fuel oil resulted in an increase of 14 percent in total cost. An increase of 50 percent in the cost of labor resulted in an increase of 10 percent in total cost. An increase of 50 percent in the other major cost items resulted in increases in total production cost of from 2 to 9 percent.

Summary and Conclusions

Cost of maple syrup production increased from 1972 to 1984 reflecting the rise in the general price level as measured by the CPI. However, the difference between the maple syrup production cost index and the CPI was as great as 18 points for 1 year. Although the maple industry cost trend may follow the trend in the CPI, characteristics of the industry may cause production costs to change more or less than changes in the CPI. For example, maple production is fuel intensive so that increased fuel oil prices have a greater influence on syrup production cost than on the CPI.

Syrup price has also increased over the period studied. However, after removing the increase caused by inflation, there was no change in either production cost or price expressed in dollars of constant value.

During the study period major shifts related to cost have occurred in the industry. The sugarhouse or syrup processing center has become the major cost center in the production process. In 1972, syrup processing accounted for 53 percent of total cost, and in 1984, 66 percent. Production cost using plastic tubing has decreased relative to production cost using buckets. In 1972, syrup production cost using tubing was 81 percent of cost using buckets. In 1984, the percentage dropped to 75 percent. Additions to existing maple operations and new operations will most likely use plastic tubing.

The analysis identified changes that could lower the cost of syrup production. In 1984, wood-fueled evaporation yielded total cost 12 percent lower than oil-fueled evaporation. Processing sweeter sap, say 3 percent sap versus 1.5 percent sap, can lower cost by 40 percent. Production cost per gallon at the 3,000-tap level is lowered by 10 percent compared to production at the 2,000-tap level. These options are not always a matter of choice for the operator. But when options are available, the operator can estimate the effect on production cost.

The analysis indicates that efforts to increase fuel efficiency and labor productivity have the greatest potential to reduce total production cost. It helps explain why an innovative technology such as sap concentration using reverse osmosis is a serious alternative to oil-fired evaporation (Sendak and Morselli 1984).

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Appendix

Table 1.—Sensitivity of total maple syrup production cost[a] to change in major cost items, 1984 costs as a base

Item	Change in cost or value of item	Change in total production cost
	Percent	
Fuel oil	+50	+14
Labor	+50	+10
Sap collection equipment	+50	+ 9
Evaporator	+50	+ 7
Interest rate	+50	+ 5
Packaging	+50	+ 5
Sugarhouse	+50	+ 2

[a] Assumes a 3,000-tap operation, tubing with vacuum and an oil-fired evaporator.

Table 2.—Standard equipment list for bucket systems

Item	Quantity
15-quart sap bucket	1 per tap
Sap bucket cover	1 per tap
Metal sap spout	1 per tap
20-quart gathering pail	2 per operation
Bucket washer	1 per operation
Snowshoes (pair)	1 per operation
Power tree tapper	1 per operation
Tapping bit	1 per operation
Bit file	1 per operation
Spark plug	1 per operation
Hand tool set	1 per operation
Tractor (prorated)	1 per operation
Sap sled	1 per operation
10-barrel gathering tank	1 per operation

Source: Huyler 1975.

Table 3.—Standard equipment list for tubing-vacuum systems

Item	Quantity
Nylon sap spout	1 per tap
5/16-inch sap tubing	15 feet per tap
1/2-inch mainline tubing	2 feet per tap
3/4-inch mainline tubing	1.2 feet per tap
1-inch mainline tubing	0.7 feet per tap
5/16-inch connector	0.05 per tap
1/2-inch connector	0.02 per tap
3/4-inch connector	0.012 per tap
1-inch connector	0.007 per tap
5/16-inch end cap	0.04 per tap
5/16-inch tee	1 per tap
4-way wye	0.02 per tap
1- x 3/4-inch reducer	0.002 per tap
3/4- x 1/2-inch reducer	0.004 per tap
Quick clamp	0.082 per tap
Aluminum fence wire	0.7 foot per tap
Quick clamp pliers	1 per operation
Wire ties	1 per operation
Wire tier	1 per operation
Fence wire stretcher	1 per operation
Spout puller	1 per operation
Sap pump	1 per operation
50-gallon vacuum storage tank	1 per operation
Snowshoes (pair)	1 per operation
Power tree tapper	1 per operation
Tapping bit, bit file and spark plug	1 per operation
Hand tool set	1 per operation

Source: Huyler 1975.

Table 4.—Standard equipment list for syrup processing by fuel type and tap size[a]

Item	Wood			Oil		
	2,000 taps	3,000 taps	4,000 taps	2,000 taps	3,000 taps	4,000 taps
Evaporator[b] (feet)	5 x 12	5 x 16	6 x 16	5 x 12	5 x 16	6 x 16
Sap storage tank capacity (gallon)						
Buckets	2,500	3,750	5,000	2,500	3,750	5,000
Tubing	3,160	4,740	6,320	3,160	4,740	6,320

[a] Additional equipment that does not vary with size of operation or fuel type includes: 30-gallon filter tank, 3- x 3-foot flat rayon filters, syrup hydrometer and cup, syrup skimmer, syrup grading set, automatic draw-off.

[b] Evaporators are fully equipped as recommended by the manufacturer including grate for wood-fired evaporators, oil burners and a 1,000-gallon fuel tank with oil-fired evaporators, arch insulation, fire brick, and retort cement as required.

Source: Huyler and Garrett 1979.

Table 5.—Variables and value used in production cost computer program, 1972 to 1984

Variable	Value	Source
Sugarhouse size (square feet)		Wells 1977
Wood-fired 2,000-tap	710	
3,000-tap	880	
4,000-tap	1,000	
Oil-fired 2,000-tap	560	
3,000-tap	650	
4,000-tap	680	
Labor		
Sap collection (hour/tap)		Huyler 1975
Buckets	0.205	
Tubing	0.160	
Syrup processing (hour/season)		Huyler and Garrett 1979
Wood-fired	140	
Oil-fired	130	
Packing (hour/gallon)		Report of the Governor's Maple Industry Task Force 1975[a]
Bulk	0.0080	
Wholesale	0.0110	
Retail (gal)	0.0167	
(qt)	0.0278	
Energy consumption		Huyler and Garrett 1979
Wood (cord/gal syrup)	0.04	
No. 2 oil (gal/gal syrup)	3.50	
Electricity (kWh/tap)	0.033	
Economic life (years)		
Buckets	30	Huyler 1975
Tubing	10	
Sugarhouse	25	Huyler and Garrett 1979
Evaporator	20	
Percentage of maple syrup sales		United States Department of Agriculture, Statistical Reporting Service 1972-1984
Retail	51.6	
Bulk	32.3	
Wholesale	16.1	

[a] Report of the Governor's Maple Industry Task Force. 1975. Unpublished, on file at USDA Forest Service, Northeastern Forest Experiment Station, Burlington, VT.

Table 6.—Source of price information for maple syrup production cost and revenue, 1972 to 1984

Item	Source
Standard equipment	
Maple equipment	G. H. Grimm Co., Rutland, VT (Annual Catalog) Leader Evaporator Co., St. Albans, VT (Annual Catalog) Reynolds' Sugarbush Co., Aniwa, WI (Annual Catalog)
Hand tool set	Sears Roebuck and Co., Chicago, IL (Annual Catalog)
Snowshoes	L. L. Bean Co., Freeport, ME (Winter Catalog)
Fuel storage tank	Webb Fuel Co., Williston, VT (personal communication)
Tractor (60-horsepower, Ford F-4000)	Yandow Sales and Service, North Ferrisburg, VT (personal communication)
Operation expenses	
Property tax rate	Real Estate Guide, Andover, MA
Wages	Vermont Department of Employment and Training, Research and Statistics Section, 1972–1982, Montpelier
Interest rate (3-month U.S. Treasury Bills)	Council of Economic Advisers
Insurance Rate	Hickok and Boardman Inc., Burlington, VT
Energy	
No. 2 fuel oil	Energy news. VT Department of Energy, Montpelier
Fuelwood	New Hampshire Department of Resources and Economic Development
Electricity	Green Mountain Power Corp., Burlington, VT (Annual Report) Central Vermont Public Service Co., Middlebury/St. Albans, VT (Annual Report)
Revenue	
Average syrup price (all sales)	United States Department of Agriculture, Statistical Reporting Service
Syrup sales proportion	United States Department of Agriculture, Statistical Reporting Service

Sendak, Paul E.; Bennink, John P. **The cost of maple sugaring in Vermont.** Res. Pap. NE-565. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1985. 14 p.

An annual maple syrup production cost series was developed for the period 1972 to 1984. Comparisons were made between plastic tubing and metal bucket technology and wood- and oil-fired evaporation. The effects of sap-sugar content and size of operation were examined together with the relationships among major cost items. The information will be useful to maple syrup producers and lenders needing financial analyses, equipment developers and manufacturers, and public policy analysts and planners.

ODC 892.68

Keywords: Cost analysis; maple sugar production

*U.S. GOVERNMENT PRINTING OFFICE: 1985-505-928:20009

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United States
Department of
Agriculture

Forest Service

**Northeastern Forest
Experiment Station**

Research Paper
NE-567

1985

Success of Trees and Shrubs in an 18-Year-Old Planting on Mine Spoil

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Manuscript received for publication 26 September 1984.

Abstract

Plantings of 25 shrub and 25 tree species on a surface mine were evaluated after 18 years and results were compared to a 4-year evaluation. Pin oak, sweet birch, European white birch, Austrian pine, and bur oak show promise of value for wood products. Several other species are useful as soil builders and site stabilizers and for wildlife habitat. Results of the evaluation suggest that mortality of some species over the past 14 years is related primarily to intraspecific and interspecific competition rather than spoil characteristics.

Cover Photo: Trees in an experimental plot and volunteering Virginia pine on acid spoils of the Lily site, Lily, Kentucky.

Introduction

There have been numerous trials of tree and shrub species to determine their suitability for vegetating surface-mined lands for wildlife habitat and forestry. Some of the earlier trials were concerned with selecting tree species that would produce forest products of commercial value. More recently, trials included species of trees and shrubs that will provide diversity in food and cover for wildlife, enhance development of soil and site conditions favorable to natural forest succession, and contribute esthetic enrichment. One such species trial was evaluated 4 years after planting by Plass (1975). In this paper we report on a followup evaluation made 18 years after planting at one of the sites reported on by Plass.

Methods

The Lily site in this study is referred to as Site 1 in the report by Plass (1975). It resulted from surface mining of the Lily coal seam in 1963 and 1964. The spoils, predominantly acid to very strongly acid grey to black shales, were graded to a nearly level topography. There was no topsoiling treatment, fertilization, or liming, and no grass or leguminous ground cover was established.

In 1965, 25 tree and 25 shrub species were planted on this site near Lily in Laurel County, Kentucky. Three tree and two shrub species were planted as replacements in 1966. Twelve blocks each of trees and shrubs, including both native and introduced species, were planted. Each species was randomly assigned to a 6- by 6-foot plot in each block. Four seedlings were planted 3 by 3 feet apart in each plot. All stock was planted bare root except rhododendron, which was planted with a small ball of nursery soil around the roots. Plass (1975) reported species survival and height of plants at the end of the fourth growing season.

In 1965, a soil sample was taken at the center of every plot in every tree and shrub block. The samples were analyzed for pH and specific conductivity by the 1:2 soil to water method, and for available phosphorus by Bray-1 extract (Black 1965). In 1983, four samples from the top 10 cm were taken from each tree block and analyzed by the same

The Lily experimental site at the time of tree plot establishment in 1965.

methods to get soils development data for the same three variables. The 1983 sampling was stratified by tree species: one sample was taken from a mimosa plot, one from an olive plot (nonspecific as to species), one from a birch plot (nonspecific as to species), and the fourth was taken next to a volunteer Virginia pine (*Pinus virginiana*) either in or adjacent to the tree blocks.

The 1983 soils data were analyzed by two-way analysis of variance (ANOVA) with tree species considered a fixed factor and tree block considered a random factor. Tukey's ω test (Steel and Torrie 1980) was performed on tree species means of the three variables where the ANOVA indicated significant differences. Percentage of plots with surviving plants (block frequency), total survival of trees, height of surviving trees and shrubs, and diameter at breast height (d.b.h.) of trees were determined. Tree and shrub heights were measured to the nearest 0.1 foot with a fiberglass measuring pole. The diameter at breast height of trees was determined to the nearest 0.1 inch with a steel d.b.h. tape. Where there were multiple tree stems, the d.b.h. of the largest stem was recorded.

Results

Tree Species

The frequency of survival (percent of plots with surviving trees of a given species) and total survival of trees are shown in Table 1. Half of the tree species maintained a survival frequency of 50 percent or better in the 12 blocks. Mimosa (silktree) had 69 percent actual survival and 100 percent block frequency, better than any other species. Crab apple had a block frequency of 83 percent at 18 years. Of the trees originally listed by Plass (1975) as commercially important based on potential value for wood products, pin oak, European white birch, sweet birch, little leaf linden, bur oak, and Austrian pine had the greatest 18th-year total survival and a frequency of 50 percent or more. Other successful species still present in 50 percent or more of the plots were thornless honeylocust, tree-of-heaven, Siberian elm, boxelder, and Russian mulberry. Several species have disappeared completely.

Table 1.—Survival of tree species, in present

Species	Frequency[a]	Total survival[b] 18 years	Total survival[b] 4 years[c]
Mimosa *Albizzia julibrissin* Durazz.	100	69	94
Pin oak *Quercus palustris* Muenchh.	91.7	40	42
Thornless honeylocust *Gleditisia triacanthos* L. f. *inermis* (Pursh) Schneid.	83.3	42	75
Japanese crab apple *Malus zumi*[d] Matsum.	83.3	38	56
Tree-of-heaven *Ailanthus altissima* Swingle	75.0	33	46
Siberian elm *Ulmus pumila* L.	75.0	33	67
European white birch *Betula pendula* Roth	66.7	27	35
Sweet birch *Betula lenta* L.	58.3	27	40
Littleleaf linden *Tilia cordata* Mill.	58.3	23	40
Boxelder *Acer negundo* L.	50.0	19	21
Bur oak *Quercus macrocarpa* Michx.	50.0	15	29
Russian mulberry *Morus alba* L. v. *tatarica* Loud.	50.0	15	17
Austrian pine *Pinus nigra* Arnold	50.0	15	29
Black mulberry *Morus nigra* L.	41.7	17	25
American smoketree *Cotinus obovatus* Raf.	41.7	15	21
Sourwood *Oxydendrum arboreum* (L.) DC.	41.7	15	15
Flowering dogwood *Cornus florida* L.	41.7	13	13
Blackgum *Nyssa sylvatica* Marsh.	25.0	6	6
Yellow birch *Betula allegheniensis* Britt.	8.3	2	35[e]
Tamarisk *Tamarix parviflora* DC.	0.0	0	71
Siberian peashrub *Caragana arborescens* Lam.	0.0	0	44
Japanese pagodatree *Sophora japonica* L.	0.0	0	29
Japanese black pine *Pinus thunbergi* Parl.	0.0	0	8
Fraser fir *Abies fraseri* (Pursh) Poir.	0.0	0	0
Cucumbertree *Magnolia acuminata* L.	0.0	0	0

[a] Percentage of plots with surviving plants at 18 years.
[b] Percent surviving plants of total number planted.
[c] Plass (1975).
[d] Reported as Hawthorn (*Crataegus* spp.) by Plass (1975).
[e] Some plots reported as yellow birch by Plass (1975) were identified as sweet birch in 1983.

While tree growth probably is not as great or as significant as it might be because of the effect of close spacing and shading, it still provides useful information on the relative performance of the tree species (Table 2). The best species in terms of mean height growth were European white birch, tree-of-heaven, Austrian pine, sweet birch, pin oak, and Siberian elm. Mean diameter growth of survivors was greatest in Austrian pine, tree-of-heaven, mimosa, European white birch, and pin oak.

Table 2.—Mean and maximum height and diameter at breast height of tree species

Species	*n*	Height		D.b.h.	
		Mean	Maximum	Mean	Maximum
		- - Feet - -		*- - Inches - -*	
Mimosa	37	19.8	30.6	4.2	7.2
Pin oak	19	23.9	38.5	3.4	6.5
Thornless honeylocust	20	17.1	32.2	2.7	4.6
Crab apple	9	13.2	14.9	—	—
Tree-of-heaven	14	29.9	36.0	4.2	8.0
Siberian elm	16	21.0	43.0	2.5	8.4
European white birch	13	37.2	37.8	3.7	5.5
Sweet birch	12	24.8	31.2	2.3	4.6
Littleleaf linden	11	8.4	17.9	0.9	3.1
Boxelder	9	11.6	27.0	0.5	4.6
Bur oak	7	17.8	23.1	2.2	3.6
Russian mulberry	6	11.4	26.5	1.6	5.1
Austrian pine	7	25.7	34.5	4.7	8.3
Black mulberry	8	12.5	19.2	1.8	2.5
Smoketree	7	11.3	16.6	1.0	2.5
Sourwood	7	16.9	23.2	2.9	4.3
Flowering dogwood	6	15.3	23.0	—	1.9
Blackgum	3	12.1	16.4	1.0	1.6
Yellow birch	1	18.8	18.8	1.9	1.9
Weighted Mean		19.2		2.9	
Mean			26.9		4.7

Shrub Species

The shrub plots have become dense thickets. The spreading habit of the shrubs along with invading species made actual survival determinations impossible, so only percent frequency of survival (presence or absence) in the blocks was determined. Twelve of the 25 species maintained themselves in at least half of the blocks (Table 3). Japanese fleeceflower maintained itself in all of the blocks, and silky dogwood in all but one. Chinese privet and thorny, autumn, and cherry olives persisted with 75 percent frequency or better and dominated the plots by overtopping many adjacent species. There were no surviving plants of six species originally planted.

Soils

Soil pH increased from a mean of 3.90 to 4.46 during the 18-year period. Soluble salts as determined by specific conductivity dropped from a mean of 0.31 mmhos/cm to 0.15 mmhos/cm, or 52 percent. Available phosphorus dropped from 6.83 ppm to 4.02 ppm (Table 4). Paired t-tests of block means showed that the changes over time in these three variables were statistically significant at the $\alpha = 0.001$ level. Spoil pH was significantly ($\alpha = 0.05$) related to the species occupying the plot in which the samples were taken (Table 5). There were no significant differences related to tree species for specific conductivity and phosphorus.

Discussion

Tree Species

There has been some mortality among most of the tree species since the last evaluation. For some species this probably is caused by overcrowding, shading, and competition for water and nutrients, more due to close spacing than to effects of the acid mine spoil. Interspecific and intraspecific competition probably was not important during the first 4 years but would have been intense sometime within the last 14 years. Standing, dead, overtopped trees were found next to larger live trees of the same species in several of the plots. Some species may not be adapted climatically to this area. Tamarisk and Siberian peashrub showed good survival after 4 years but were absent after 18 years.

Pin oak was one of the most successful tree species. Its general form was excellent, and height and diameter growth were among the best of the trees on the site. Pin oak seems to be a good choice in this region for surface-mine spoils that are high in clay content and subject to summer droughts. It normally is an important species on wet, intermittently flooded lowlands and on upland flats with heavy soils subject to winter and spring waterlogging and summer droughts. Interspecific competition limits the importance of pin oak on better sites (Fowells 1965). Forty-two percent survival after 4 years with loss of only one more tree in the following 14 years indicates that initial site conditions and not interspecific competition were the principal causes of mortality at the Lily site. Acceptable survival and good growth indicate the value of pin oak for long-term economic returns. Seed usually is not produced before about 25 years of age (Fowells 1965). However, some seed apparently were being produced at the Lily site because pin oak seedlings were found. These seedlings may have a limited future because pin oak is moderately shade intolerant.

Table 3.—Survival and height of shrubs

Species	Frequency[a]	Mean Height[b]
	Percent	*Feet*
Japanese fleeceflower *Polygonum cuspidatum* Sieb. & Zucc.	100	9
Silky dogwood *Cornus amomum* Mill.	91.7	8
Chinese privet *Ligustrum sinense* Lour.	83.3	13
Thorny olive *Elaeagnus pungens* Thunb.	83.3	16
Autumn olive *Elaeagnus umbellata* Thunb.	75.0	19
Cherry olive *Elaeagnus multiflora* Thunb.	75.0	17
Amur privet *Ligustrum amurense* Carr.	75.0	11
Multiflora rose *Rosa multiflora* Thunb.	75.0	9
Indigobush *Amorpha fruticosa* L.	66.7	6
Oakleaf hydrangea *Hydrangea quercifolia* Bartr.	58.3	6
Cotoneaster *Cotoneaster acutifolius* Turcz.	50.0	6
Tatarian honeysuckle *Lonicera tatarica* L.	50.0	10
Coralberry *Symphoricarpus orbiculatus* Moench	41.7	5
European barberry *Berberis thunbergii*[c] DC.	41.7	4
Blueberry *Vaccinium corymbosum* L. v. *glabrum* Gray	33.3	5
Rugosa rose *Rosa rugosa* Thunb.	25.0	—
Red honeysuckle *Lonicera korolkowi* Staph. v. *zabelii* Rehd.	8.3	5
Althea *Hibiscus syriacus* L.	8.3	7
Arrow-wood *Viburnum dentatum* L.	8.3	—
Scotch broom *Cytisus scoparius* L.	0.0	—
Rhododendron *Rhododendron catawabiense* Michx.	0.0	—
Russian olive *Elaeagnus angustifolia* L.	0.0	—
Chinese lilac *Syringa chinensis* Willd.	0.0	—
Dewberry *Rubus* spp. Hort. v.	0.0	—
Blackberry *Rubus* spp. Hort. v.	0.0	—

[a] Percentage of plots with surviving plants.
[b] Average of estimated height of tallest plant in plot.
[c] Reported as *Berberis vulgaris* by Plass (1975).

Table 4.—Mean soil chemical characteristics of tree blocks at the Lily site in 1965 and 1983[a]

Tree	Mean pH value[b]		Specific conductivity		Available phosphorus[c]	
	1965	1983	1965	1983	1965	1983
			mmhos/cm		*ppm*	
1	4.24	4.60	0.20	0.13	7.6	3.1
2	4.37	5.00	.21	.19	7.1	5.3
3	3.76	4.20	.27	.14	5.1	2.8
4	3.89	4.58	.25	.15	6.0	4.0
5	4.02	4.70	.27	.16	7.2	4.0
6	3.96	4.30	.18	.14	6.2	3.6
7	3.52	4.50	.31	.18	6.1	4.4
8	3.83	4.55	.36	.18	8.1	4.7
9	4.33	4.48	.33	.13	9.6	4.2
10	3.66	4.18	.53	.13	6.5	3.4
11	3.86	4.28	.33	.11	7.9	5.9
12	3.41	4.20	.44	.10	4.6	2.8
Mean	3.90	4.46	.31	.15	6.8	4.0
Sd	.303	.244	.102	.028	1.38	.96

[a] Mean difference over time for each variable was statistically significant, $\alpha = .001$, paired t-test.
[b] 1965 mean for every plot; 1983 mean for four samples per block.
[c] Bray-1 extractant.

Table 5.—Comparison of mean soil pH value, specific conductivity, and available phosphorus under four tree genera in the tree blocks, 1983

Species	pH	Specific conductivity	Phosphorus
		mmhos/cm	*ppm*
Mimosa	4.71 a	.16 a	4.0 a
Birch	4.48 ab	.13 a	4.5 a
Olive	4.44 ab	.15 a	3.6 a
Pine	4.22 b	.13 a	3.9 a

Means for the same variable followed by the same letter are not significantly different, $\alpha = 0.05$, Tukey's ω.

An experimental tree plot on the Lily site showing forest development in 1985, 20 years after tree planting on acid spoils.

European white, sweet, and yellow birches survived in similar numbers through the first 4 years. However, survival of European white birch and sweet birch declined by about one-third, and yellow birch nearly disappeared by the 18th year. Survival of European white and sweet birch was equal at 18 years, but unequal distribution of survivors gave European white birch a higher survival frequency.

European white birch was the best of the birches in height and diameter growth. Height growth of both European white birch and sweet birch was better than the overall average of tree species included in this test. On "average" sites in New York and Pennsylvania, sweet birch can grow to 4 inches d.b.h. at age 20 (Fowells 1965). The largest sweet birch trees on the Lily site achieved this size. Yellow birch at this location is well south of its normal lowland growth range; the warmer climate plus the xeric nature of the surface-mine environment probably is responsible for its poor performance.

In a study of seven birch species planted on a variety of coal-mine spoils in Pennsylvania, Davidson (1976, 1979) found that European white birch had significantly better survival than sweet and yellow birches; yellow birch had the least height growth. Davidson noted the best birch growth was on spoil with a pH of 4.0, though performance was satisfactory down to pH 3.3. Deer browsing damaged the birches in Pennsylvania; yellow and sweet birches were browsed more heavily than other species. Davidson recommends not planting these two species in areas with high deer populations. Improvement of the soil surrounding the birches probably is their greatest contribution to the forest ecosystem. At the Lily site, a developing A horizon in the spoil around them was noted.

Total survival and block frequency of Austrian pine was 15 and 50 percent. Average height of this tree was 25.7 feet, third best of the species tested. The mean d.b.h. of 4.7 inches and its maximum of 8.3 were largest and second largest, respectively. Many of the surviving trees were on plots characterized as "extremely acid" and "very strongly acid" (Soil Survey Staff 1957). The tallest individual was on an extremely acid plot. Only one plot had more than one surviving tree. In several plots a smaller dead pine stood next to the survivor. This indicates that intraspecific competition may have been intense for this species. Keys et al. (1980) cited competition and spoil acidity as factors contributing to mortality of Austrian pine planted on mine spoils. They also determined that seed source and elevation were important in determining the success of this species. Austrian pine has value as a timber species in Europe, but is used primarily as an ornamental in the United States (Little 1979). Our results indicate that more research on management of Austrian pine on surface-mine environments is justified.

Bur oak had a modest tolerance of initial site conditions; 29 percent of the planted trees survived to 4 years of age (Plass 1975). Competition apparently decreased this number by half but bur oak still had a block frequency of 50 percent. Height and diameter growth were less than the weighted mean for all species. Bur oak's growth rate at Lily is not unusually low for this species, however. Plantation growth rates reported by Fowells (1965) bracket the height and diameter growths found on the Lily plots. Bur oak rapidly develops a deep, spreading taproot system. Mature trees may have a root biomass and volume about equal to the aboveground portion of the tree. Such a characteristic gives this tree extreme drought tolerance and gives the species high value as a slope stabilizer. Bur oak tolerates a variety of soil conditions but favors limestone soils in Kentucky (Fowells 1965). This species should have good long-term economic potential on sites with less competition and better spoils. Bur oak was rated as one of the better performing hardwoods on surface-mined lands in Ohio (Larson and Vimmerstedt 1983) and in Missouri and Kansas (Vogel 1977).

Survival of littleleaf linden was 40 percent at 4 years but over the next 14 years it dropped to about half that. The species was included in this test because of potential commercial value. However, survival, and especially growth, do not warrant its further consideration for wood product purposes on this or similar sites.

Blackgum was the least successful in growth of the surviving commercial tree species planted on the site. However, blackgum was an important volunteer tree in the natural plant communities on the site (Thompson et al. 1984). Plass (unpublished progress report 1967) noted the small size of the blackgum planting stock, which may have been primarily responsible for poor survival. The remaining tree species in the experimental plots had little or no timber product value; they were included for other reasons.

Mimosa, a nitrogen-fixing legume, was present in all blocks and had the highest survival at 4 and 18 years. However, most of the mimosa trees were multistemmed and degenerating, with many dead stems per tree, poor form, and dieback of the tops. Many of the surviving mimosa were on spoils initially characterized as very acid, so soil acidity per se may not be the main factor determining the survival of mimosa on these spoils. Mimosa may continue to persist at Lily because of sprouting and suckering near the plantings. This semitropical tree, introduced from Asia, is naturalized in the southeastern United States (Little 1979). Although it is mainly planted as an ornamental, it appears to have value on surface mines as a nitrogen fixer and soil modifier, and as a nurse crop for commercial tree species. Its stem form and attractive flowers are esthetically pleasing.

Thornless honeylocust, a less-armed form of the common honeylocust, showed very good 4-year and reasonably good 18-year survival. Nearly half of these trees were less than 1 inch in d.b.h., and their mean height was less than the mean height (weighted average) of all the trees measured. Only one individual's growth exceeded the minimal 4-inch d.b.h. that is desirable for posts, so this tree's economic potential at the Lily site was poor. Thornless honeylocust is drought resistant but ample water is required for good growth (Fowells 1965). Primary values of this tree are for nitrogen fixation and wildlife food. Where penetration is not inhibited by compaction, the taproots of thornless honeylocust may descend 12 to 20 feet (Fowells 1965) to function as slope stabilizers and as biological pumps for raising nutrients to the surface from deep spoil layers. Thornless honeylocust may have greater value on spoils less acid than the ones at the Lily site. Its growth might be improved through proper management.

Crab apple (*Malus zumi*), reported as hawthorn (*Crataegus* spp.) by Plass (1975), had 56 percent survival at 4 years. At 18 years it still had a block frequency of 83 percent and an actual percentage survival of 38 percent. This Asian species was present only as a small tree. Good survival and production of fruit make it a species worthy of consideration in wildlife plantings.

Tree-of-heaven, introduced from China as an ornamental (Little 1979), has become naturalized over much of the United States and has a wide environmental tolerance. It had a 33 percent overall survival rate at the Lily site. This was one of the largest

trees on the site and reproduction by suckering was evident. It has value primarily as an ornamental.

Siberian elm maintained 75 percent block frequency and had reasonably good survival after 18 years. This introduction from northern China and Siberia (Little 1979) produced the largest tree (43 feet tall and 8.4 inches in d.b.h.) in the planted blocks, but the mean growth for this species was not exceptional.

Survival of flowering dogwood is low (13 percent) but there has been no mortality over the last 14 years. Height growth was reasonable for an understory tree. This species also was an important invading tree on the Lily site (Thompson et al. 1984). Dogwood litter is high in nutrients, especially calcium. Thomas (1969) found that flowering dogwood is important in maintaining the calcium cycle in pine plantations on poor soils in Tennessee. This species could contribute to soil building and fertility maintenance in the mine spoils. Dogwood is a favored deer browse and its fruit is eaten by birds (Fuller 1980).

American smoketree is one of the rarer native trees in America and it is normally found on calcareous soils (Fernald 1950). The survival and growth of this tree indicate it is not suited to the Lily site or sites with similar site conditions.

Sourwood had 15 percent survival with no mortality after the fourth year. This suggests that site quality was a greater obstacle to this species than competition. Another possible reason for poor early survival is the small size of planting stock noted by Plass (unpublished progress report 1967). Its growth is about average for established trees on the Lily site. It is a frequent pioneer on disturbed sites and we have noted it invading other surface-mined areas. Thompson et al. (1984) documented sourwood as one of the most important invading native species on the Lily site. The fruit is eaten by wildlife, and the twigs are browsed by deer. Honey produced from sourwood nectar is a much desired product. Its potential value for reclamation on sites such as this needs more investigation.

Black mulberry and Russian mulberry, both naturalized from Asia (Little 1979), had relatively poor initial survival (Plass 1975). However, mortality was quite low over the next 14 years. This indicates that stands would have a good chance if they could be maintained through the early years. The same is true for dogwood and sourwood. Neither the black nor Russian mulberry formed sizable trees except for one Russian mulberry individual which was 5.1 inches in d.b.h. and 26.5 feet tall. These species have value as wildlife food but growth and survival do not warrant their inclusion in a tree mix where survival is of great importance.

The 21 percent survival of boxelder at 4 years and 19 percent survival at 18 years indicates that initial site conditions, not competition, are responsible for its poor performance. Although this normally is a small tree of mesic and fertile soils, it is an important volunteer in tree plantations on spoils in the Midwest (Ashby et al. 1980). The fruits are eaten by squirrels and birds.

Because of its good early survival, Plass (1975) recommended planting tamarisk on spoils as an ornamental. However, there were no surviving tamarisk at 18 years. This suggests that although the species could withstand initial site conditions, it is unable to tolerate competition on poor sites. It also may be unadapted climatically. Tamarisk is considered a pest in the Southwest, where it readily colonizes along irrigation ditches and around reservoirs. It apparently requires excessive ground water or free water to thrive. Results with tamarisk at Lily demonstrates the importance of long-term studies for making recommendations on species suitable for surface-mine plantings.

Japanese pagodatree, Japanese black pine, and Siberian peashrub all had surviving individuals at the end of the fourth year but none at the 18th year. Fraser fir, and cucumbertree did not survive to the fourth year. None of these species are recommended for mine reclamation.

Shrub Species

The complete overgrowth of many of the shrub blocks by the species planted therein made it impossible to determine whether a shrub's presence represented survival of one or several planted individuals. Frequency of survival can serve as a guide to overall survival.

Japanese fleeceflower was present in all plots. This species, naturalized from Asia, is a shrub-like herb. It had developed into dense clumps spreading away from the point of planting. The species formed a dense stand of stems in several small gullies and showed great value as an erosion arrester and wildlife food. It has been reported as tolerant of extremely acid spoils (Ruffner 1978). Patterson (1976) indicates that Japanese fleeceflower may become an important weed due to its spreading nature.

Silky dogwood persisted in 92 percent of the blocks. It makes an excellent deer browse and the fruit is consumed by birds. Persistence of this species, besides its tolerance to acid conditions, also may be due to its shade tolerance. Because of its persistence and value for wildlife, we recommend planting it for wildlife habitat.

The two *Ligustrum* species, Chinese privet and Amur privet, both survived with a frequency of 75

percent or better. These two species were naturalized from China (Staff, L. H. Bailey Hortorium 1976). Their tolerance of surface-mine spoil conditions and production of wildlife food and cover make them species worthy of consideration in reclamation.

Thorny, autumn, and cherry olives were successful in their frequency of survival and in their role as soil builders. These nitrogen-fixing shrubs formed thick canopies overhead and developed a rich leaf-litter mulch on the soil surface. The relatively high nitrogen content of their leaves probably was responsible for the rapid litter breakdown and formation of a rich organic horizon in the top 1 to 2 inches of the soil profile. These species, naturalized from Asia (Staff, L. H. Bailey Hortorium 1976), provide good deer browse and the fruit is used by birds and mammals. In some areas, autumn olive is regarded as a pest because of its spreading nature; it also has been used widely as a nurse species with trees on surface-mine spoils (Vogel 1981).

Multiflora rose, a naturalized shrub from China (Staff, L. H. Bailey Hortorium 1976), persisted in 75 percent of the plots. The flowers have esthetic value and wildlife may use the plants for cover and the fruits for food. This shrub spreads, forms impenetrable tangles of thorny clones, and can cause serious problems in most land uses (Patterson 1976). Despite its virtues for wildlife habitat, we do not recommend multiflora rose for reclamation of surface-mined land.

Indigobush persisted on two-thirds of the plots. Like the olives, it contributes to soil development through nitrogen fixation. This native shrub also has value as wildlife food and cover.

Oakleaf hydrangea persisted on 58 percent of the plots. It has a striking appearance with its large leaves and white flowers. It is one of the lowest growing of the successful shrubs and is shade tolerant. Its primary value may be for esthetic purposes.

The remaining shrub species had a plot frequency of 50 percent or less, which hints at low survival. Five species—Scotch broom, catawba rhododendron, Chinese lilac, dewberry, and blackberry—were absent after 18 years, though there were survivors at the fourth year. Failure of Russian olive by the fourth year was attributed to poor planting stock (Plass, unpublished progress report 1967). Even though the planted horticultural varieties of blackberry failed, the native blackberry species are invading the Lily site.

Spoil Characteristics

The analysis of the spoils shows evidence of good soils development. A mean pH increase of about 1/2 unit and a halving of the soluble salts as determined by specific conductivity show the ameliorating effect of time and perhaps vegetation (Table 4). The decline in Bray-1 extractable phosphorus from 6.8 to 4.0 ppm is equivalent to a loss of 5.5 pounds per acre, but more than this certainly is tied up in vegetation biomass. Both vegetation and time, appear to have had a significant influence on soil development. The nature and thickness of the O horizon varied with the kind of vegetation above it. A high organic-matter A_1 horizon was notable under the canopies of nitrogen-fixing trees and shrubs. The 1983 soil samples had a significantly higher pH where taken under mimosa than where taken under Virginia pine (Table 5). Samples from under the olives and birches had intermediate pH's not significantly different from either mimosa or Virginia pine.

Summary and Conclusions

At 18 years after planting, pin oak, sweet birch, European white birch, Austrian pine, and bur oak show promise of value for wood products on sites such as this. Tree species of little or no commercial timber value such as mimosa, thornless honeylocust, tree-of-heaven, and Siberian elm showed some usefulness as soil builders and site stabilizers. Shrubs with promise for ground cover, erosion control, soil building, and sources of wildlife food and habitat include silky dogwood, Chinese and amur privets, thorny, autumn, and cherry olives, indigobush, oakleaf hydrangea, and Japanese fleeceflower.

Several tree species showed significant decreases in survival between the fourth and 18th years, which may indicate that death is due more to intraspecific and interspecies competition than to site conditions.

Chemical conditions in the spoils have been modified during the 18-year period. The pH has increased, while specific conductivity and soil phosphorus have dropped significantly. Tree species had a significant influence on spoil pH. Spoil pH under the leguminous mimosa tree was significantly higher than under Virginia pine.

Results of this study and observations made at this site suggest that with proper choice of species even acidic surface-mined lands such as the Lily site have a long-term potential for forest production. Some economically important species can survive and have respectable growth. There is a need for studies to determine optimum management of these species in similar environments. Noncommercial and ornamental species also have a role on these sites as environmental modifiers, soil builders, and food and cover for wildlife.

This study was started during a period when extensive regrading, amendment, and herbaceous covercropping of surface-mined lands were not required and generally were not carried out. Results of current reclamation practices may well differ from those achieved here. The information gained still is applicable to abandoned mined lands on which site conditions are similar to those present on the Lily site at the inception of this study.

The importance of long-term evaluation of studies is made clear by the drastic changes in survival of several species such as yellow birch, tamarisk, Siberian peashrub, and Scotch broom. For example, on the basis of 4 years of data, Plass (1975) reasonably concluded that tamarisk and yellow birch were adapted to sites such as this. But results at 18 years did not bear this out.

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Reports the status of 18-year-old plantings of 25 tree and 25 shrub species on surface-mine spoil. The value of the species for wood products, wildlife habitat, site stabilizers, and soil builders is discussed.

ODC : 232.11:114.449.8

Keywords: Surface mine reclamation; trees; shrubs; survival; growth; species trials

*U.S. GOVERNMENT PRINTING OFFICE: 1985-461-[illegible]:[illegible]11

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United States
Department of
Agriculture

Forest Service

Northeastern
Station

Research Paper
NE-568

1985

Butt Log Quality of Trees in Pennsylvania Oak Stands

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Manuscript received for publication 22 October 1984

Abstract

Describes the distribution of sawtimber trees by diameter at breast height (d.b.h.) and grade for eight hardwood species in upland oak stands of Pennsylvania. The proportion of trees by d.b.h. and grade revealed differences between species. The quality of northern red oak, white oak, and yellow-poplar appeared inherently better than that of red maple, chestnut oak, and a group of other hardwoods. Grade predictions by size and species allow more precise timber appraisals and enable managers to evaluate alternative management strategies more accurately.

Introduction

The dollar value of a hardwood tree depends largely on its suitability for conversion into various types of wood products. Some hardwood trees are converted to high-value products such as face veneer or First and Second and Select grade factory lumber; others are used only for their fiber or as fuelwood.

Hardwood log and tree grading systems have been used since the early 1900's by foresters, timber buyers or sellers, and others to appraise timber values. USDA Forest Service standard grades for hardwood factory lumber logs have not changed since they were first published in 1949 by the Forest Service's Forest Products Laboratory. However, guides for applying the rules have been revised and now provide greater detail and more clarification (Rast et al. 1973). Lumber grade yields associated with the log grades have been tabulated and expanded to include other hardwood species (Hanks et al. 1980).

In addition to the grades for factory lumber logs, specifications have been developed for other major use classes of logs, including veneer, construction, and local use. Grade specifications within each class of logs are designed to separate logs into value groups based on product requirements.

It is possible to determine the precise relative value of a tree if yields in factory lumber grades or other product classes are available by log grade, species, and diameter at breast height (d.b.h.). Tree-value conversion standards reported by (Mendel et al. 1976) measure a tree's relative worth based on the quantity and quality of its expected yield of 4/4 (1-inch) lumber. This approach to tree or stand evaluation is beneficial to foresters and others because it is easy to use, objective, and provides a realistic ranking of relative tree or stand values. The only information needed is d.b.h., merchantable height, tree grade, and species.

Unfortunately, there is little information on tree grades in most forest inventories or growth and yield simulators. Although we can not determine accurately the value of individual trees, it is still possible to evaluate stands. This requires an appropriate distribution of trees for each species that gives the percentage by grade in each d.b.h. class. Such grade distributions have been described mathematically for six hardwood species on the Allegheny Plateau (Ernst and Marquis 1979). Trimble (1965) presented free-hand curves that described the grade distribution for factory-grade butt logs for six hardwood species in West Virginia. It was apparent from these findings that there were large differences between species in the d.b.h.-grade relationship and by geographic area.

Our objective in this study was to develop estimates of the d.b.h.-grade relationship for an expanded list of species for upland oak stands of Pennsylvania. These distributions could be used to evaluate typical stands for timber sale appraisals or used in growth simulators to assign a grade to individual trees. Although the specific grade distributions developed in this study apply only to the Pennsylvania oak stands, the methodology is applicable to other timber types or geographic areas.

Methods

Data

Our data on log grades were extracted from 10-point cluster plots used in the USDA Forest Service's 1978 forest survey of Pennsylvania. Original field plots were first screened to select all plots where oak and hickory species constituted a plurality of the stand basal area. From 506 plots representing the oak-hickory type in Pennsylvania, we tabulated the number of trees by species, grade, 1-inch diameter class, and productivity class. Our sample of hardwood sawtimber trees, excluding all conifers, consisted of 15,716 observations by species and grade (Table 1). Sugar maple, hickory, and beech were later pooled with other hardwoods because data were insufficient for analysis.

Grades were assigned by survey field crews using Forest Service standard grades for hardwood factory lumber logs for log grades 1 through 3. If the butt log failed to meet specifications for a factory lumber log but met specifications of Forest Service standard hardwood construction logs (Tie and Timber logs), it was assigned grade 4. The major factors that affect quality for the tie and timber logs are size and condition of log defects, straightness, and soundness of heart (Rast et al. 1973). Culls and other sawtimber-size trees not meeting these specifications were assigned grade 5. Trees generally were graded on the butt 16-foot section rather than on the shorter sections permitted by the grading rules. However, to prevent underestimating log quality, if a 12-or 14-foot section qualified as a higher grade compared to the entire log, then the higher grade was assigned to the entire 16-foot log.

Four productivity classes originally were tabulated on the basis of the ability of the site to produce wood, and were expressed as growth in cubic feet (ft^3) per acre per year. The best sites were those capable of producing a mean annual increment greater than 120 ft^3/acre; the mean annual increment on the poorest site was less than 50 ft^3/acre. Intermediate sites ranged from 50 to 84 and from 85 to 120 ft^3. We later found that productivity class had no significant effect on the distribution of grades by d.b.h. class. As a result, this variable was dropped from our analyses.

Table 1.—Number of trees by grade and species

Species	No. 1	No. 2	No. 3	No. 4	No. 5	Total	Percent by species
White oak	215	448	1021	79	86	1849	12
Chestnut oak	202	739	1851	66	411	3269	21
Northern red oak	690	999	1570	41	181	3481	22
Other oaks	258	477	1034	94	87	1950	12
Red maple	45	190	816	94	204	1349	09
Yellow-poplar	190	211	344	65	32	842	05
Walnut ash	44	133	260	5	100	522	03
Sugar maple	10	32	87	9	30	168	01
Hickory	37	85	278	51	32	483	03
Beech	2	18	47	43	29	139	01
Other hardwoods	73	275	775	77	464	1664	11
Total	1,766	3,587	8,033	624	1,656	15,716	--
Percent	11	23	51	04	11	--	100

Analysis

The proportion of trees in each grade within a diameter class was computed and plotted over the range of diameters for a species (Fig. 1). From these plotted distributions we were able to hypothesize mathematical models to describe the grade distributions. A nonlinear model was developed to fit the distribution of grade 1 trees of the form:

$$Y(i,1) = \beta_0 * (1-EXP(\beta_1 * (D_i - C_O)))^{**}\beta_2 \qquad (1)$$

where:

$Y_i,1$ = proportion of trees in the ith diameter class that are grade 1

D_i = midpoint of the ith diameter class

C_O = a constant to be estimated. Interpreted as the minimum d.b.h. that qualifies as a grade 1 tree; hence, C_O = 15.5 inches

$\beta_0, \beta_1, \beta_2$ = model parameters to be estimated:

$\beta_0 > 0; \beta_1 < 0$

Data analysis indicated that the percentage of grade 1 trees reached a maximum at a d.b.h. of 18 to 20 inches. For most species, the proportion of grade 1 trees declined beyond 20 inches in d.b.h. The coefficient, β_0 in model 1, is the asymptote and represents the maximum percentage of grade 1 trees. We determined the approximate value of β_0 by reading the maximum value from free-hand curves. Values of β_1 and β_2 were then computed by nonlinear regression using data through the 20-inch d.b.h. class.

The shape of the grade 2 frequency distribution was more difficult to describe mathematically, but when grade 1 and grade 2 trees were combined the shape of the curve resembled that for model 1 (Fig. 1). We used the combined grade 1 and 2 data to fit model 1 and then by subtracting the estimate for grade 1 obtained the estimated percentage for grade 2 trees for a specified diameter. The model parameter β_0 was read from the hand-fitted curves as before. Minimum d.b.h. for a grade 2 hardwood log is 13 inches, so C_O was assigned the value 12.5. Estimates of β_1 and β_2 were computed by nonlinear regression for all data through the 20-inch d.b.h. class.

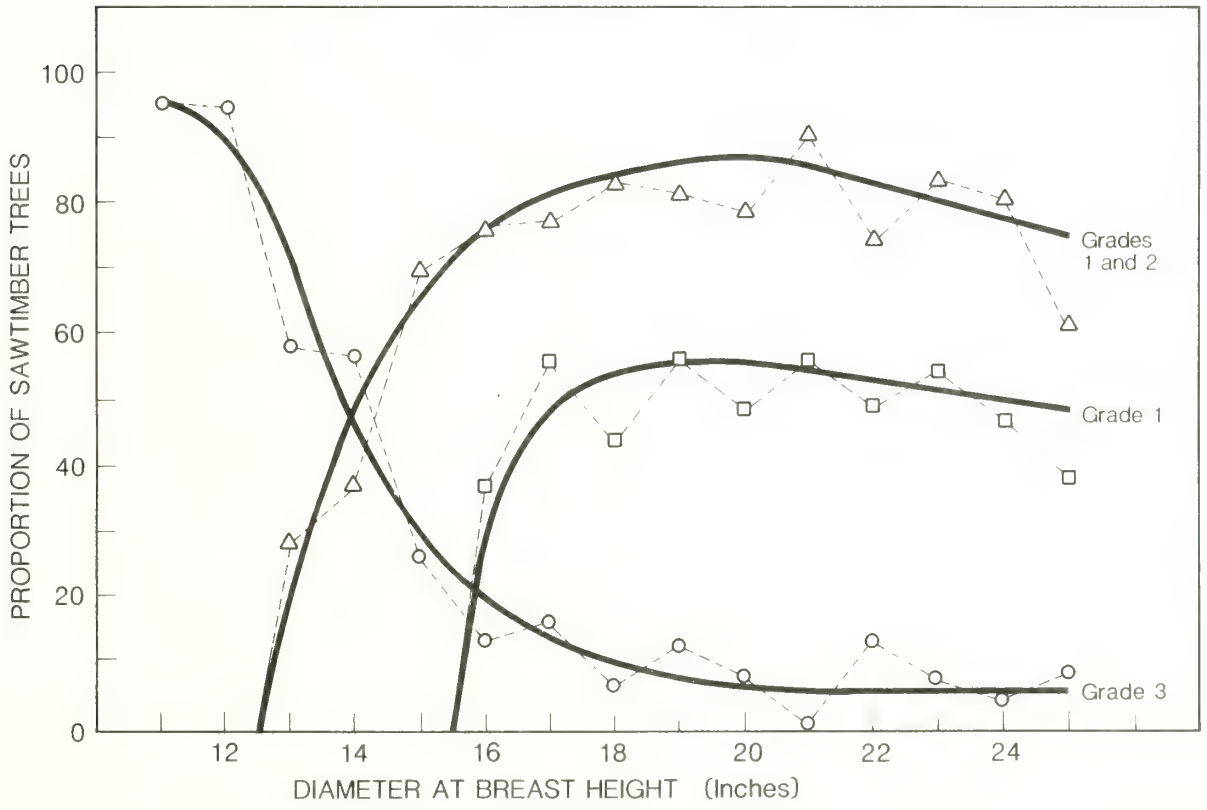

Figure 1.--Distribution of butt-log grade for white oak trees.

For all trees larger than 20 inches in d.b.h., we used a linear regression model to estimate the proportion of trees in grade 1 and the combined log grades 1 and 2. This regression was conditioned so that when the d.b.h. was 20.5 inches, model 1 or 2 provided identical estimates. The intercept term, α_0 in the model:

$$Y = \alpha_0 + \alpha_1 EXP(D_i - 20.5) \quad (2)$$

was set equal to the solution of model 1 using a d.b.h. of 20.5 inches. Linear regression was used to estimate the value of α_1 for each species.

The distribution of grade 3 trees was fitted to a nonlinear model of the form:

$$Y(i,3) = \alpha_0 - \beta_0 * (1 - EXP(\beta_1 * (D_i - C_0)))^{**} \beta_2 \quad (3)$$

where:

Y(i,3) = proportion of trees in the ith diameter class that are grade 3

C_0 = a constant. The minimum sawtimber size hardwood was 11.0 inches in d.b.h., hence, C_0 = 11.0 inches

$\alpha_0, \beta_0, \beta_1, \beta_2$ = model parameters to be estimated. $\alpha_0 > 0; \alpha_0 > \beta_0; \beta_1 < 0$

Approximately 95 percent of white oak trees that are 11.0 inches d.b.h. are grade 3 (Fig. 1). The parameter α_0 was set equal to this value, or 0.95. Figure 1 also shows that the proportion of grade 3 trees seems to have some minimum value which is approached asymptotically with large trees. Therefore, we determined the value of this asymptote as $(\alpha_0 - \beta_0)$ from the free-hand curve value for a 25-inch tree. Data from all diameter classes were used to estimate the parameters β_1 and β_2 as before.

Trees that were grade 4 made up a relatively small percentage of all trees for most species and accounted for only 4 percent of the entire sample (Table 1). We did not attempt to separate grade 4 from grade 5 trees since both grades combined accounted for only 15 percent of the total, and both grades represent low value or unmerchantable material. Plotted data indicated that grade 5 trees, or culls, generally tended to increase with d.b.h. class, particularly for trees more than 20 inches d.b.h. The percentage of grade 4 and 5 trees combined was obtained for any d.b.h. class by substracting the combined percentages of grades 1, 2, and 3 from unity.

Results

We were unable to detect significant differences in grades due to site quality, so this variable was dropped from the final analyses. Also, sample size was too small or poorly distributed across d.b.h. classes to obtain reliable equations for hickory, sugar maple, or beech, so these species were pooled with other hardwoods.

Estimated parameters and statistics are given for predicting the proportion of trees in each grade in Tables 2, 3, and 4. From observed and predicted values we calculated R^2 values for each species and grade and the root mean square residual. For a given species, higher computed R^2 values were obtained for grade 3 trees than grade 1 or grade 1 and 2 combined (Table 4). However, the root mean square residual indicates that data fitted the model for each grade about equally well since there was little difference in the statistic between the models. Some species, generally those with the most observations, provided slightly better estimates of the parameters. The root mean square residual ranged from 0.05 or 0.06 to 0.15 for each of the three models. Overall, the models seemed to fit northern red oak, white oak, and other oaks somewhat better than the other species, particularly red maple and the black walnut/ash group.

Model parameters for white oak were used to predict the proportion of trees by grade for each diameter class (Table 5). As expected, similar calculations for other species revealed considerable differences between species. Table 6 gives the percentage of combined grade 1 and 2 trees; red oak, white oak, and yellow-poplar usually have inherently better quality than chestnut oak, red maple, or the group of other hardwoods.

Discussion

The results of this study indicated large differences among species in the d.b.h.-grade relationship. Similar findings were reported by Trimble (1965), who believed that these differences were due to inherent differences in branching habit and frequency of dormant buds. There are similar inherent differences between Allegheny hardwood species (Ernst and Marquis 1979). The latter found the highest proportion of grade 1 or 2 trees in the black cherry/yellow-poplar group, whereas the beech/birch group consisted of higher proportions of grade 3 or lower quality trees.

Table 2.—Model parameters for predicting the proportion of grade 1 trees

Species	Trees ≤ 20.5 inches d.b.h.			Trees ≥ 20.5 inches d.b.h.		R^2	Root mean square residual
	β_0	β_1	β_2	α_0	α_1		
White oak	.56	-1.1948	0.8908	.5587	-.0144	.14	.064
Chestnut oak	.44	-0.8340	0.9384	.4336	+.0072	.39	.096
Northern red oak	.70	-3.3948	1.8049	.7000	-.0123	.09	.068
Other oak	.62	-1.3828	1.5821	.6190	-.0369	.34	.115
Red maple	.37	-1.6440	1.1589	.3699	-.0158	.19	.134
Yellow-poplar	.75	-0.7511	1.0043	.7324	-.0303	.26	.148
Walnut/ash	.64	-0.8071	1.3390	.6249	-.0526	.70	.107
Other hardwoods	.40	-0.5001	1.0931	.3782	+.0791	.69	.119

Table 3.—Model parameters for predicting the proportion of grade 1 and grade 2 trees combined

Species	Trees ≤ 20.5 inches d.b.h.			Trees ≥ 20.5 inches d.b.h.		R^2	Root mean square residual
	β_0	β_1	β_2	α_0	α_1		
White oak	.88	-0.6316	1.1970	.8733	-.0240	.89	.060
Chestnut oak	.72	-0.6916	1.1076	.7168	-.0433	.53	.109
Northern red oak	.90	-0.8966	0.9596	.8993	-.0422	.66	.082
Other oak	.79	-0.6716	1.1276	.7859	-.0444	.84	.058
Red maple	.59	-0.6477	0.8341	.5872	-.0467	.32	.131
Yellow-poplar	.94	-0.3663	0.7354	.9028	-.0170	.79	.094
Walnut/ash	.76	-0.6362	0.9442	.7556	-.0689	.30	.154
Other hardwoods	.61	-0.4853	1.0606	.5967	-.0382	.30	.122

Table 4.—Model parameters for predicting the proportion of grade 3 trees

Species	All trees ≥ 11.0 inches d.b.h.				R^2	Root mean square residual
	α_0	β_0	β_1	β_2		
White oak	.95	.89	-0.6596	4.4001	.96	.056
Chestnut oak	.81	.72	-0.7590	6.8966	.80	.110
Northern red oak	.92	.85	-1.1836	10.3264	.94	.061
Other oaks	.90	.80	-0.6081	3.7632	.93	.057
Red maple	.78	.59	-0.6761	3.6106	.53	.159
Yellow-poplar	.96	.91	-0.4939	1.7693	.89	.083
Walnut/ash	.86	.75	-0.3791	1.6353	.65	.126
Other hardwoods	.64	.52	-0.3926	1.7900	.82	.077

Table 5.—Predicted grade distribution of white oak by d.b.h. class.

D.b.h.	Grade 1	Grade 2	Grade 3	Grade 4 and 5
11	--	--	.950	.050
12	--	--	.914	.086
13	--	.184	.724	.092
14	--	.489	.488	.023
15	--	.667	.308	.025
16	.275	.491	.196	.038
17	.476	.343	.132	.049
18	.535	.312	.098	.055
19	.552	.311	.080	.057
20	.558	.313	.070	.059
21	.552	.309	.065	.074
22	.537	.300	.063	.100
23	.523	.290	.061	.126
24	.508	.281	.061	.150
25	.494	.271	.060	.175
26	.480	.261	.060	.199
27	.465	.252	.060	.223

Table 6.—Percentage of sawtimber trees with grade 1 or 2 butt log, by species and d.b.h. class.

D.b.h.	White oak	Chestnut oak	Northern red oak	Other oak	Yellow-poplar	Walnut ash	Red maple	Other hardwoods
13	18	18	34	19	25	22	20	12
14	49	44	67	47	50	48	40	30
15	67	58	81	63	64	61	49	42
16	77	65	86	71	74	68	54	49
17	82	68	88	75	80	72	56	54
18	85	70	89	77	85	74	58	56
19	86	71	90	78	88	75	58	58
20	87	72	90	78	90	76	59	59
21	86	70	88	76	89	72	59	58
22	84	65	84	72	88	65	58	54
23	81	61	79	68	86	58	58	50
24	79	56	75	63	84	51	57	46
25	76	52	71	59	83	45	57	43

Our sample data on tree quality represent a much broader spectrum of various forest conditions than was reported in earlier studies. Because of this diversity in ownerships, management practices, and forest conditions, our sample quality data should represent average stand conditions for the Pennsylvania upland oak type. Although our sample included data on some of the same species discussed in earlier studies, no comparisons were attempted because both geographic areas and forest conditions differed. It should be noted that the quality of trees in individual stands may vary widely from the average values reported here because of the great variation in forest conditions sampled.

Our grade distributions also differ from earlier results in that beyond a d.b.h. of 20 inches all species show a decline in the proportion of grade 1 and 2 trees. Many of our sample stands have been cut indiscriminately over the years, leaving culls or low-value trees to occupy the lands.

The 31-percent drop in grade 1 or 2 walnut or ash trees between 20 and 25 inches may reflect the fact that high-value, high-quality trees that are more than 20 inches in d.b.h. are more likely to be cut.

The computed percentages by grade and d.b.h. class for each of the various species are useful when estimating stand or tree values for typical stands where specific grade information is lacking. In broad regional economic analyses, grade distributions are helpful in determining current and projected timber resources by species, quality class, and value. When grade distributions are used in conjunction with growth simulators, more precise economic evaluations are possible for alternative management strategies.

The equations presented here provide a means of building grade predictions into growth simulators for eight species groups. Thus, as the simulator grows a tree in height, d.b.h., and volume, we can change the grade over time with these equations. For example, if we have a 14-inch grade 3 white oak, what is the probability of it becoming grade 1 or grade 2 when it reaches 16 inches? Using Table 5 or the equations, we can determine that about 29 percent of such grade 3 trees will become grades 1 or 2 by the time they grow to 16 inches (.488-.196=.292).

The grade distributions by d.b.h. class (Table 5) should be an important reminder that quality and, therefore, value are closely linked to size. Less than 50 percent of 14-inch white oak trees are expected to be better than grade 3. If these trees grow 4 more inches, then 85 percent should qualify as grade 1 or 2. Goho and Wysor (1980) showed that most logs more than 17 inches in scaling diameter that were delivered to sawmills were grade 1. However, they added that the most frequent scaling diameter of logs delivered at their sample sawmills in West Virginia was only 12 to 14 inches; thus, these logs were of low quality. Since the stumpage price of grade 1 or 2 trees is several times that of grade 3 trees, managers should look at the economics of growing their small sawtimber trees a few more years so that more would qualify as grade 1 or 2.

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Describes the distribution of sawtimber trees by diameter at breast height (d.b.h.) and grade for eight hardwood species in upland oak stands of Pennsylvania. The proportion of trees by d.b.h. and grade revealed differences between species. The quality of northern red oak, white oak, and yellow-poplar appeared inherently better than that of red maple, chestnut oak, and a group of other hardwoods. Grade predictions by size and species allow more precise timber appraisals and enable managers to evaluate alternative management strategies more accurately.

ODC: 853:561.5:652.3

Keywords: Grading; quality; value

*U.S. GOVERNMENT PRINTING OFFICE: 1985-505-028:20028

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**Northeastern Forest
Experiment Station**

Research Paper
NE-569

1985

Survival and Growth of Black Walnut Families After 7 Years in West Virginia

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Manuscript received for publication 18 October 1984

Abstract

Average survival, 7-year stem diameter, and stem diameter growth differed significantly among 34 black walnut families planted in West Virginia. Average total height, height growth, and diameter at breast height were not significantly different among families. Families were from seed collected in West Virginia, Pennsylvania, North Carolina, and Tennessee. The 7-year results indicated that although survival was significantly different among families, differences in height growth were not well enough defined to recommend sources for planting.

Introduction

Black walnut (*Juglans nigra* L.) grows well on many sites in West Virginia and is native to all parts of the state. However, it is only a small part of timber resource in West Virginia. The most recent forest survey for West Virginia shows that only about 43,000 acres of the 11.5 million acres of commercial forest land are classed as black walnut type (Bones 1978). The estimated volume of black walnut is 107 million cubic feet in trees larger than 5 inches in diameter at breast height (d.b.h.), and 207 million board feet in trees larger than 9 inches in d.b.h. Seventy-three percent of the cubic volume and 50 percent of the board-foot volume is in trees less than 15 inches in d.b.h.

Because of heavy cutting of individual trees, and disregard for regeneration, black walnut seed sources have been eliminated from many of the sites where they occurred naturally in West Virginia. However, under proper management on suitable sites, the amount of black walnut in West Virginia forests probably can be increased substantially.

This paper reports on the 7-year growth and survival of black walnut seedlings planted on the Fernow Experimental Forest near Parsons, West Virginia. The seedlings were grown from seeds collected at several locations in or near the southern and central Appalachians.

The objective of the outplanting is to bring together genetically different seedlings from several locations for the development of a black walnut seed orchard in West Virginia. Also, performance of black walnut plantations, in West Virginia has not been well documented. This report provides early growth data and cultural information that could be useful to those interested in growing walnut.

Methods

Families

Thirty-four families of 1-0 black walnut were outplanted in the spring of 1976 on the Fernow Experimental Forest near Parsons, West Virginia. Families from four states are represented in the West Virginia outplanting; 21 are from West Virginia, 7 from Pennsylvania, 4 from North Carolina, and 2 from Tennessee (Table 1). The spread between the most easterly and westerly family is approximately 600 miles. The distance between the most northern and southern family is about 350 miles. The outplanting site is about 100 miles north of the center of the collection areas.

As far as is known, all of the collections were from single trees and many were located around farmsteads. It is possible that some of parent trees are not native to the locale where they are growing, because farmers often planted varieties of nursery stock for nut production rather than for timber. Differences in elevation among families ranged from 600 feet for some of the bottom-land sites to more than 2,350 feet for upland and mountain sites.

Study Area

Because of space limitations, two areas were logged and cleared of slash for the outplanting. Both areas are relatively level, with slopes not exceeding 10 percent. The first area is at an elevation of 2,800 feet above sea level. The soil is a Belmont silt loam derived from the Greenbrier limestone formation. The other area is at an elevation of 2,720 feet. The soil on this area is mapped as a Meckesville silt loam, which is colluvial in origin. The soil has some limestone influence because it lies just downslope from the limestone-derived Belmont series.

Annual precipitation on the Fernow Experimental Forest is 58 inches and is well distributed throughout the year. Mean annual temperature is 48° F and the length of the frost-free season is about 145 days. The Belmont soil study area has an oak site index between 80 and 85; the Meckesville site is about site index 80 for oak.

Both areas were forested before planting. The stands were 70- to 75-year-old mixed hardwoods, and included a high proportion of black cherry (*Prunus serotina* Ehrh.), yellow-poplar (*Liriodendron tulipifera* L.), northern red oak (*Quercus rubra* L.), sugar maple (*Acer saccharum* Marsh.), and white ash (*Fraxinus americana* L.). On the Belmont area there were a few scattered black walnut trees.

Sawtimber and pulpwood trees larger than 5 inches in d.b.h. were harvested. The remaining stems were felled and removed along with the slash by winching with a tractor from the perimeter of the area.

Planting and Culture

The study design was a randomized complete block. Six rectangular blocks were laid out parallel with the contour. Four were on the Belmont soil and two were on the Meckesville soil. Trees were planted in 5-tree row plots at a spacing of 6 by 12 feet, i.e., trees were 6 feet apart in rows 12 feet apart; 1-0 seedlings were planted in 8-inch diameter holes prepared with a power auger. Average height of seedlings was about 1.0 foot at planting time and roots were pruned to about 10 inches. To keep the trees in a free-to-grow position, competing vegetation was mowed four times during the early life of the plantation. Hand-held power brush cutters were used.

Table 1.—Location and characteristics of black walnut parent trees

Family number	State	County	Latitude N	Longitude W	Parent tree		
					D.b.h.	Merchantable height	Site
			o ′	*o ′*	*Inches*	*Feet*	
1578	TN	Morgan	36-10	84-45	[a]	[a]	[a]
1615	TN	Wayne	35-15	87-45	[a]	[a]	[a]
1582	NC	Rowan	35-30	80-30	[a]	[a]	Upland
1588	NC	McDowell	35-45	82-00	[a]	[a]	Mountain
1589	NC	Alexander	35-50	81-15	[a]	[a]	[a]
1607	NC	Buncombe	35-45	82-30	[a]	[a]	[a]
1600	PA	Berks	40-30	76-00	14.0	24.0	Open grown
1602	PA	Cumberland	40-15	77-15	[a]	[a]	[a]
1603	PA	Chester	40-00	75-30	40.5	67.0	[a]
1604	PA	Chester	40-00	75-30	24.3	46.0	[a]
1605	PA	York	40-00	76-45	[a]	[a]	[a]
1606	PA	Cumberland	40-15	77-15	18.0	24.0	
1666	PA	Greene	39-45	80-15	18.9	[a]	Cove
1625	WV	Upshur	39-00	80-15	16.0	32.0	Bottom land
1627	WV	Lewis	39-00	80-30	18.9	[a]	[a]
1628	WV	Braxton	38-40	80-45	14.0	16.0	Bottom land
1630	WV	Braxton	38-40	80-45	14.0	16.0	Bottom land
1632	WV	Braxton	38-40	80-45	20.0	16.0	Bottom land
1633	WV	Gilmer	39-00	80-50	14.0	16.0	Bottom land
1636	WV	Tucker	39-05	79-40	16.0	32.0	Bottom land
1638	WV	Pendleton	38-40	79-20	14.0	32.0	Bottom land
1641	WV	Pocahontas	38-15	80-00	19.0	15.0	Bottom land
1642	WV	Pocahontas	38-15	80-00	18.0	50.0	Upland
1645	WV	Greenbrier	38-00	80-25	25.0	50.0	Bottom land
1646	WV	Greenbrier	38-00	80-25	15.4	50.0	Upland
1649	WV	Monroe	37-40	80-30	19.2	90.0	Upland
1650	WV	Summers	37-45	80-45	11.2	50.0	Bottom land
1652	WV	Boone	37-50	81-40	14.0	45.0	Upland
1653	WV	Boone	37-50	81-40	14.0	40.0	Upland
1654	WV	Boone	38-05	81-50	24.6	15.0	[a]
1655	WV	Kanawha	38-15	81-25	23.7	40.0	Bottom land
1658	WV	Clay	38-20	81-10	9.6	60.0	Bottom land
1660	WV	Tucker	39-05	79-40	22.0	75.0	Bottom land
1661	WV	Monongalia	39-40	80-00	25.0	[a]	Upland

[a] Data not recorded.

Results

Site Differences

At the end of seven growing seasons, seedlings growing on the Belmont soil and those on Meckesville soil did not differ significantly in total height, 7-year height growth, d.b.h., stem diameter at 1.0 inch above ground, or stem diameter growth.

Survival

At the end of 7 years, average survival was 84 percent for all blocks and families (Table 2). Survival among families was significantly different at the 5-percent level. Fifty percent of the families exceeded the mean survival for all families and blocks. Plotting showed no apparent correlations between survival and latitude and longitude of the parent trees.

Height Growth

Average total height for all blocks and families was 6.4 feet at the end of 7 years (Table 2). There was no significant difference in

Table 2.—Performance of black walnut families at the end of 7 years

Family	County and state	Average height	Percent mean height	Average 1980–82 height growth	Percent mean height growth	Average stem diameter	Percent mean stem diameter	Average stem diameter growth	Percent mean stem diameter growth	Percent survival	Percent mean survival
		Feet		*Feet*		*Inches*		*Inches*			
1652	Boone, WV	7.4(1) [a]	116	2.2	129	1.3	118	1.0	125	87	104
1660	Tucker, WV	7.4(1)	116	2.3	135	1.4	127	1.1	138	97	115
1600	Berks, PA	7.2(3)	113	2.4	141	1.2	109	1.0	125	90	107
1589	Alexander, NC	7.1(4)	111	2.0	118	1.1	100	0.9	113	97	115
1666	Greene, PA	7.1(4)	111	2.1	124	1.4	127	1.1	138	93	111
1588	McDowell, NC	6.9(6)	108	1.9	112	1.2	109	1.0	125	83	99
1649	Monroe, WV	6.9(6)	108	1.8	106	1.1	100	0.9	113	93	111
1607	Buncombe, NC	6.7(8)	105	1.9	112	1.2	109	0.9	113	87	104
1638	Pendleton, WV	6.7(8)	105	1.5	88	1.2	109	1.0	125	80	95
1641	Pocohontas, WV	6.7(8)	105	2.0	118	1.1	100	0.9	113	70	83
1655	Kanawha, WV	6.7(8)	105	2.1	124	1.1	100	0.9	113	83	99
1604	Chester, PA	6.6(12)	103	1.9	112	1.1	100	0.9	113	80	95
1628	Braxton, WV	6.6(12)	103	1.6	94	1.2	109	0.9	113	77	92
1646	Greenbrier, WV	6.6(2)	103	1.6	94	1.1	100	0.8	100	80	95
1642	Pocohontas, WV	6.5(15)	102	2.1	124	1.1	100	0.9	113	87	104
1615	Wayne, TN	6.4(16)	100	1.5	88	1.0	91	0.8	100	87	104
1625	Upshur, WV	6.4(16)	100	1.6	94	1.1	100	0.8	100	93	111
1627	Lewis, WV	6.4(16)	100	1.8	106	1.1	100	0.8	100	87	104
1632	Braxton, WV	6.4(16)	100	1.8	106	1.0	91	0.7	88	97	115
1578	Morgan, TN	6.3(20)	98	1.5	88	1.1	100	0.8	100	83	99
1653	Boone, WV	6.3(20)	98	1.6	94	1.2	109	0.9	113	97	115
1654	Boone, WV	6.3(20)	98	1.8	106	1.1	100	0.9	113	83	99
1661	Monongalia, WV	6.3(20)	98	1.6	94	1.2	109	0.9	113	83	99
1603	Chester, PA	6.2(24)	97	1.6	94	1.1	100	0.8	100	70	83
1582	Rowan, NC	6.1(25)	95	1.4	82	0.9	82	0.7	88	73	87
1630	Braxton, WV	6.1(25)	95	1.5	88	1.1	100	0.8	100	87	104
1633	Gilmer, WV	6.1(25)	95	1.6	94	1.0	91	0.8	100	87	104
1636	Tucker, WV	6.1(25)	95	1.1	65	1.0	91	0.7	73	67	80
1658	Clay, WV	6.0(29)	94	1.8	106	1.0	91	0.7	73	80	95
1605	York, PA	5.9(30)	92	1.6	94	1.0	91	0.8	100	73	87
1606	Cumberland, PA	5.7(31)	89	1.5	88	1.0	91	0.8	100	93	111
1650	Summers, WV	5.1(32)	80	1.2	71	0.8	73	0.6	75	87	104
1602	Cumberland, PA	4.6(33)	72	1.4	82	0.8	73	0.6	75	67	80
1645	Greenbrier, WV	4.6(33)	72	1.5	88	0.7	64	0.5	63	73	87
	Average	6.4		1.7		1.1		0.8		84	

[a] Numbers in parentheses are family rank.

total height among families. Thirty-eight percent of the families exceeded the plantation mean height of 6.4 feet. Of the five families whose average height exceeded 7.0 feet, two were from West Virginia, two from Pennsylvania, and one from North Carolina.

From 1980 to 1982, height growth ranged from 1.1 to 2.4 feet and averaged 1.7 feet. There was no significant difference in 2-year height growth among families. In general, families with the best 2-year growth also were the tallest families.

Seven-year average height growth for all families and blocks was 5.4 feet; there was no significant difference in 7-year average height growth among families. Average annual height growth for the 7-year period was 0.77 foot.

Stem Diameter Growth

Stem diameter 1.0 inch above ground ranged from 0.7 to 1.4 inches and averaged 1.1 inches over all blocks and families (Table 2). There was significant difference in average stem diameter among families. The Tucker County, WV, (1660) and Greene County, PA, (1666) families were significantly different only from family 1645, Greenbrier County, WV, according to Tukey's studentized range test. Average stem diameter of the Tucker and Greene County families was 1.4 inches. The average stem diameter of 68 percent of the families exceeded the plantation mean of 1.1 inch.

Average 7-year stem diameter growth was 0.8 inch for all blocks and families and differed significantly among families at the 5-percent level. The Berks County, PA, (1600), Tucker County, WV, (1660), and Greene County, PA, (1666) families were significantly different only from the Greenbrier County, WV, (1645) family; the latter had the slowest stem diameter growth. Average 7-year stem diameter growth was 1.0 inch for the Berks County family and 1.1 inches for the Tucker and Greene County families.

Diameter at Breast Height

Diameter at breast height ranged from 0.3 to 0.7 inch and averaged 0.6 inch for all families. There were no significant differences in d.b.h. among families.

Stem Form

At this time, many of the seedlings have widely divergent forks (Fig. 1). According to Schlesinger and Funk (1977), much of this type of forking is due to lateral branch

Figure 1.—Black walnut tree showing a widely divergent fork.

Summary and Discussion

development after leader tips have been killed back by late spring frosts, deer browsing, or insect attacks. Corrective pruning has been advocated to develop better walnut form, but Schlesinger (1982) recommended allowing trees to straighten naturally if possible. Lateral pruning is recommended to remove branches and stubs that might cause defects in the wood on the lower bole. In view of Schlesinger's recommendation, we decided against corrective pruning to see if family differences in form will develop in later years.

Family Ranking

When families were ranked by total height, there were no great differences among the top 16 families (only 1 foot). Nor did ranking by height result in differences among families by geographic origin. The two best performing families were Tucker County, WV, (1660) and Boone County, WV, (1652), though progeny from several locations in Pennsylvania and North Carolina also ranked high.

At the end of 7 growing seasons, some differences among families are apparent. Survival, average stem diameter, and average 7-year stem diameter growth differed significantly among families, but average total height, 1980-82 height growth, and d.b.h. did not.

Some of the best performing families have origins considerably distant from the planting site. The 7-year results indicated that seed collections from most of the 34 sources, probably would grow well in West Virginia.

In general, survival in West Virginia compares favorably to a plantation on a cleared forested site in southern Illinois and on an old field in Maryland (Krajicek 1975; Little et al. 1975). However, total height at the Illinois and Maryland sites was considerably better than that in the West Virginia outplanting for a similar period. The apparent slower growth in West Virginia can be attributed partially to top dieback of undetermined origin that affected many trees during the first 5 years. Top dieback has declined during the past 2 years; this should result in increased height growth.

Current seed-source recommendations for black walnut state that sources from 200 miles south of the intended planting site and 50 miles north can be planted and expected to grow well (Schlesinger and Funk 1977). Deneke et al. (1980) stated that it appears safe to move seed from untested black walnut trees south to north but never from north to south. They add that for optimum growth, seedlings can be moved at least 100 miles (but no more than 200 miles) from south to north. The more conservative figure should be used in the northern one-half and western one-third of the species range. Deneke et al. (1980) also suggested that unless seed needs are critical, east to west transfer of seeds other than between adjacent zones should be avoided.

The Tucker County, WV, outplanting is situated approximately 100 miles south of the most northern source, 250 miles west of the most easterly source, 250 miles north of the most southern source, and 280 miles east of the most westerly source. In addition, because the West Virginia site is somewhat higher in elevation than most of the family origin sites, movement distances must be adjusted to account for this. Nevertheless, most of the families have survived and performed reasonably well in West Virginia. All of the surviving trees are in a free-to-grow position and this condition will be maintained. Stem form on many trees is less than desired but corrective pruning will not be undertaken at this time. Natural straightening is occurring on some trees and this will be documented for future family correlations.

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Average survival, 7-year stem diameter, and stem diameter growth differed significantly among 34 black walnut families planted in West Virginia. Average total height, height growth, and diameter at breast height were not significantly different among families. Families were from seed collected in West Virginia, Pennsylvania, North Carolina, and Tennessee. The 7-year results indicated that although survival was significantly different among families, differences in height growth were not well enough defined to recommend sources for planting.

ODC 232.11:176.1

Keywords: Progeny test; black walnut; height growth

☆U.S. GOVERNMENT PRINTING OFFICE: 1985-505-028:20015

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**Northeastern Forest
Experiment Station**

Research Paper
NE-570

1985

Key Algorithms Used in GR02: A Computer Simulation Model for Predicting Tree and Stand Growth

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Manuscript received for publication 27 December 1984

Abstract

The Vermont Woodland Resource Analysis Program (VWRAP) is an interactive computer program designed to help forest-land owners make decisions. GR02 is a simulation model written as a subprogram in VWRAP for predicting individual tree and stand growth over time. The model can be characterized as an individual tree, distance-independent model. It performs five major functions during each run: (1) updates diameter at breast height, (2) updates total height, (3) estimates mortality, (4) determines regeneration, and (5) updates crown class. The key algorithms used in GR02 are presented.

Introduction

An inventory of standing timber is one of the main requirements in the preparation of a forest management plan. However, an inventory is static, and it is only valid for the time when the data were collected. One method of making the inventory dynamic is through simulation. By simulating changes that take place in the growing forest, an inventory taken at one time can be projected to some future time.

In Vermont, 90 percent of the commercial forest land is privately owned (Kingsley 1977). Excluding forest industry, corporate ownership, and forest land owned by private organizations, there are 74,000 individual owners of 3 million acres of commercial forest land in Vermont. A system that integrates a static concept of forest inventory with the dynamics of growth simulation can improve decisions made by forest-land owners and managers of this land.

The Vermont Woodland Resource Analysis Program (VWRAP) is designed to help forest-land owners make decisions; VWRAP consists of three computer programs: DATA2, YIELD, and GR02. Data from a forest inventory collected in a prescribed format are entered into a computerized data base via DATA2, an interactive program. The user can then produce a summary inventory of the woodlot on a stand-by-stand basis with the interactive program YIELD.

Long-term projections of growth for trees in the data base can be obtained with GR02, a computer simulation model for predicting individual tree and stand growth over time. The model is an individual tree, distance-independent model with both continuous and discrete variables (Ek and Dudek 1980). It can project the growth of stands composed of mixtures of species in all-aged or even-aged stands. The model, written in FORTRAN-20, version 5, is designed to run on a DEC-System 20 computer using the TOPS-20 operating system.

In this paper we present the key algorithms used to model the growth of individual sample trees and sample plots from which stand growth is inferred. The "Vermont Woodland Resource Analysis Program (VWRAP) User's Manual" describes how to use the model.[1]

[1] A copy of the manual can be obtained by writing: Extension Forester, School of Natural Resources, University of Vermont, Burlington, Vermont 05405.

Model Philosophy

Trimble (1969) reported that crown class is the most important predictor of the diameter growth of trees. We tested and confirmed Trimble's conclusion using radial increment measurements from core samples in Vermont. Given a number of diameter-growth predictor variables to choose from—d.b.h., crown length, crown width, basal area, crown class, and vigor class—for a given species on the same site, crown class was the best overall predictor of current diameter growth at breast height (Trimble 1969). Trimble's result suggested a method that was both simple and reliable.

The model relies heavily on crown class, dominant, codominant, intermediate, and overtopped (Trimble 1969), because of the statistical correlation between crown class and diameter growth. The detailed model description that follows shows that the computational algorithms that use crown class for growth prediction are relatively simple and quick to execute.

Diameter growth is projected on the basis of a tree's crown class. The total height of each sample tree is updated during a simulation run; new relative heights are computed, and Monte-Carlo techniques are used to determine a tree's crown class based on its current relative height.

For simplicity in introducing the model, the preceding discussion has ignored several other important factors in tree growth. Among these are species, site index, stocking density expressed by basal area per acre, species-specific response to release, and damage as a result of injury or disease. These factors are treated in the sections that follow.

A Dynamic Hypothesis

To use crown class as a growth predictor, it is necessary to know the crown class of a tree at any stage in its development. The growth simulator must be able to determine a tree's crown class at any point in time. This problem was solved empirically, using measurements taken from sample plots scattered throughout northern and central Vermont. Figure 1 illustrates the solution and represents the dynamic hypothesis which is the key concept in the simulation model.

Figure 1 shows the proportion of trees in a particular crown class as a function of relative height.

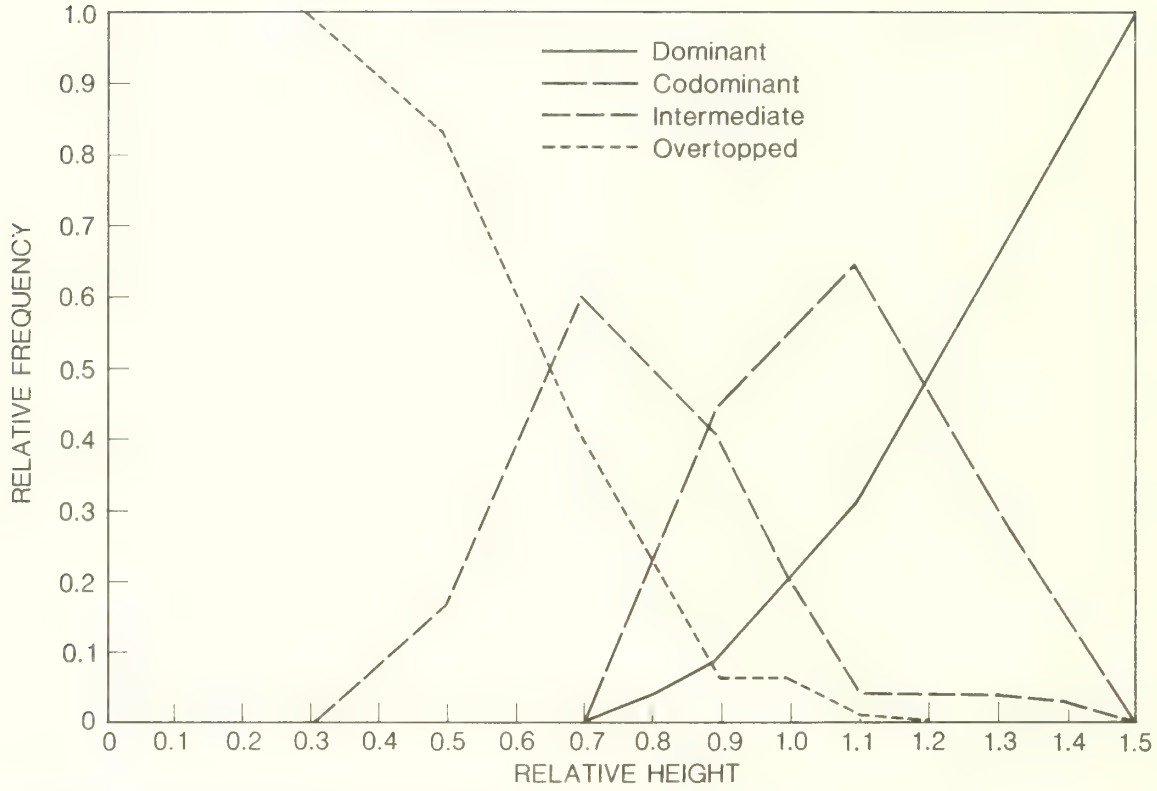

Figure 1.—Relative frequency of crown class as a function of relative tree height or height of tree expressed as a proportion of canopy height.

The proportions sum vertically to 1 at each relative height. As a tree's relative height increases, it is more likely to be in one of the higher crown classes, thus increasing its annual radial-growth rate. As a tree's relative height decreases, because it is overtopped by surrounding trees, it is more likely to be in a lower crown class, thus decreasing its annual radial-growth rate.

An individual tree's relative height depends on the height of surrounding trees on the plot. Relative height of the i^{th} tree on a sample plot is defined by the expression:

$$RH_i = H_i/\overline{H} \quad (1)$$

where

RH_i = relative height of the i^{th} tree,

H_i = total height of the i^{th} tree,

and

$\overline{H}$ = canopy height.

The canopy height, $\overline{H}$, is the weighted average height of the trees on the plot, where each tree's total height has been weighted by the tree's basal area. For variable-radius plots, it follows that the canopy height is the simple average height of the sampled trees.

The largest diameter trees on a plot make up the canopy, whereas the smaller diameter trees shape the understory. This agrees with the observation that one can remove a large number of smaller diameter (understory) trees from an area with little effect on the height of the canopy. The relative heights of the remaining trees are changed little by removing the smaller trees. With this model, growth rates of the remaining trees also change little. However, removing the larger trees from the same area reduces the canopy height, changes the entire relative height distribution, and thrusts the remaining trees into higher crown classes with a resulting increase in their overall growth rate.

Initializing GR02

Tree data are entered into GR02 by plot. In GR02, each sample plot is expanded to 1 acre, regardless of whether the information was obtained from variable-radius or fixed-area plots, before the simulation begins. Each of these 1-acre plots is treated independently as if there were n independent forests all growing at the same time within the model.

This process associates a frequency per acre with each sample tree on a plot. This frequency or expansion factor is used to compute the per-acre contribution of each sample tree to a given variable. For example, multiplying a tree's total biomass by its frequency per acre gives its contribution to the total biomass per acre for that plot.

Stand information tables, on the other hand, are the result of averaging all of the information contributed by the independent sample plots. Growth characteristics depend only on information associated with a single plot; stand table information depends on data supplied from all the plots entered into the simulation.

By not aggregating plot information during the growth simulation, the heterogeneity of the forest is maintained. Different parts of the forest will grow at different rates depending on site characteristics and tree species composition.

Basal Area

Tree basal area is the basal area (in square feet) associated with a sampled tree. Tree basal area per acre is defined as the product of tree basal area of a sample tree and its corresponding frequency per acre. For example, when a 10-factor prism is used to sample trees in the inventory process, a single 10-inch-diameter tree on an expanded sample plot represents 18.3 simulator trees per acre. During the model initialization process, a frequency of 18.3 trees per acre is associated with this sample tree. The tree basal area per acre of this sample tree equals the product of the tree basal area (0.5454 ft^2) and the sample tree frequency (18.3 trees per acre), or 10 ft^2 per acre. Total basal area per acre is defined as the sum of all the tree basal areas per acre on the same sample plot.

Key Algorithms in the Growth Model

The GR02 model performs five major functions during each run: (1) updates diameter at breast height, (2) updates total height, (3) estimates mortality, (4) determines regeneration, and (5) updates crown class. Each function is treated in detail in the following sections. Together, they provide the mechanisms for modeling the dynamics of growth of a forest.

Updating Diameter at Breast Height

The diameter at breast height outside bark is updated once each growing season during a simulation. First, radial increment inside the bark is determined for each sample tree; radial increment is converted to diameter increment outside the bark; and diameter increment is added to the current diameter outside bark to give updated breast height diameter.

Estimating the annual radial increment. On the basis of an analysis of 432 core samples taken throughout the State of Vermont, the annual radial increment (inside bark), RINC, was determined to be primarily a function of species, crown class, site index, and stand density.

Within a given crown class (dominant, codominant, intermediate, and overtopped), the minimum radial increment for trees in stands with a total basal area per acre of 100 ft^2 and greater is determined from the expression:

$$MNRINC = X_0 + X_1 (SITE) \quad (2)$$

where

MNRINC = minimum radial increment (mm) (100 ft^2 BA/A and greater),

SITE = site index at breast height age 50,

and

X_0, X_1 = species dependent coefficients.

Similarly, the maximum radial increment for 40 ft^2 and lower basal area is determined from the expression:

$$MXRINC = X_0 + X_1 (SITE) \quad (3)$$

where

MXRINC = maximum radial increment (mm) (40 ft^2 BA/A and lower).

Within a given crown class and between 40 and 100 ft² of basal area, linear interpolation gives:

$$RINC = MNRINC + \frac{MXRINC - MNRINC}{100 - 40} (100 - LBAPA) \quad (4)$$

where

RINC = radial increment (40 ft² <BA/A <100 ft²)

and

LBAPA = total basal area per acre.

Coefficients for expressions (2) and (3) were estimated for annual radial increment (in millimeters) for the following species: red spruce, white pine, hemlock, red maple, sugar maple, yellow birch, white birch, American beech, white ash, and northern red oak (Appendix, Table 6). Two additional sets of coefficients were developed for all hardwood species and for all softwood species. These are used to determine radial increment for species not included here.

If more appropriate coefficients are available from another source for a species we did not include, users can add them to the program or can substitute one of the available sets. The simulation program, and VWRAP in general, were designed to easily accommodate user modifications.

Trees are classified during the field inventory by condition and damage class. Trees with live, intact tops showing no signs of damage are assigned a radial increment as calculated previously. All other trees suffer an arbitrary degradation in radial increment by a factor between 0 and 1 selected at random from a rectangular distribution by the program. In other words, because no data were collected to correlate growth with damage, the expected value for the growth rate of damaged trees is assumed to be half the rate of undamaged trees.

To obtain the diameter increment outside bark, radial increment is first doubled, then converted to diameter increment outside bark by dividing by the species-specific ratio of diameter inside bark to diameter outside bark. The species-specific ratios were estimated by regression analysis of the trees in the growth-rate data base (Table 1). The values for an additional 12 species were obtained from Martin (1981). Other species are assigned a value of 0.926 for this ratio.

When trees change crown class, the model gradually changes diameter increment (Forrester 1961). Diameter increments are weighted by species-specific response times which have been developed from the shade-tolerance ratings assigned to various species (Spurr and Barnes 1980). Using these weighting factors causes shade-tolerant trees to take three growing seasons to respond fully to a change in crown class, whereas shade-intolerant species may take as long as 15 years.

Table 1.—Average DIB/DOB ratios, by species, for growth-rate trees

Species	DIB/DOB ratio	n
American beech	.930	48
Northern red oak	.917	53
Red maple	.937	47
Sugar maple	.913	59
White ash	.915	47
White birch	.948	35
Yellow birch	.915	38
Eastern hemlock	.916	37
Eastern white pine	.929	42
Red spruce	.936	26

Updating Total Height

The total height of each sample tree is updated once each growing season during a simulation run; GRO2 uses information obtained from site-index curves to update height. Site-index curves used in GRO2 were obtained from Hampf (1965) for red spruce, eastern hemlock, and eastern white pine; from Carmean (1978) for red maple, American beech, and northern red oak; and from Curtis and Post (1962) for sugar maple, yellow birch, white birch, and white ash.

Information in site-index curves. Site-index curves are the family of curves showing the total height for a given species plotted as a function of age at breast height for different site-index values. Within a foot or two, most of the published curves can be expressed as:

$$HGHT = TMXH + (4.5 - TMXH)e^{-T/THTC} \quad (5)$$

where

HGHT = total height (feet),

TMXH = tree maximum height (feet),

T = breast height age (years),

and

THTC = tree height time constant (years).

Breast height age is the independent variable; the maximum height (TMXH) and height time constant (THTC) are parameters of the particular curve chosen. When T equals zero in expression (5), the height is 4.5 feet; when T is very large, the total height is approximately equal to the maximum height.

Height increment (HINC) can be written as:

$$HINC = [\frac{1}{THTC}] (TMXH - HGHT) \quad (6)$$

Equation (6) is the approximate solution to equation (5), which fits the site-index curves. It is a powerful tool for simulation because it gives the rate of height growth as a function of the height and not the age of the tree.

The two constants, TMXH and THTC, are obtained for any site-index curve by fitting equation (5) exactly to two points on the curve. The values of TMXH and THTC were obtained by using an iterative approximation technique. The reader is cautioned against a strictly biological interpretation of the two constants because the shape of some of the curves implies values that we would not expect to observe in the field.

In GRO2, site-index values are grouped into 10-foot classes (Table 2). Values of TMXH and THTC for 10 species and seven site-index classes within species are contained in GRO2 (Appendix, Table 7). Currently, other hardwoods use the values for yellow birch, and other softwoods use the values for white pine. Values for other species can be added, or existing values changed.

Annual height-increment modifier. Understory trees grow taller more slowly than overstory trees. The height-growth modifier quantifies this observed change in rate of height growth. If the sample tree belongs to the intermediate or overtopped crown classes, the computed height increment is multiplied by the tree height-growth modifier, THGM.

We assumed that the maximum height constant, TMXH, is not affected for understory trees, but that the height time constant, THTC, becomes larger. If THTC1 is the time constant for dominant and codominant trees of the species and site under consideration, and THTC2 is the time constant for an understory tree, the height-growth modifier is defined as the ratio:

$$THGM = THTC1/THTC2; THTC2 > THTC1 \quad (7)$$

Table 2. Site-index classes used in GRO2

Number	Site-index values	Site-index class
1	00-44	40
2	45-54	50
3	55-64	60
4	65-74	70
5	75-84	80
6	85-94	90
7	95+	100

Height-growth modifiers were calculated from the calibration data for each of 10 species, other hardwoods, other softwoods, and for the intermediate and overtopped crown classes. Substituting for THTC1 and THTC2 in equation (7) and simplifying yields:

$$THGM = \frac{\ln [(HGHT2 - TMXH)/(4.5 - TMXH)]}{\ln [(HGHT1 - TMXH)/(4.5 - TMXH)]} \quad (8)$$

Potential height, HGHT1, was read from the site-index curve; actual height, HGHT2, was observed from the calibration data; and TMXH was estimated from the same site-index curve. Averages for each species and understory crown class were calculated and are stored in GRO2.

Mortality

The mortality segment of GRO2 was adapted from Buchman (1979). The estimated annual probability of a tree dying is given by the expression:

$$MR = [1.0 + \exp(A + B\ DINC^C)]^{-1} + D \quad (9)$$

where

MR = mortality rate,

DINC = exponentially weighted diameter increment outside bark (inches/year),

and

A, B, C, D = species specific parameters (Appendix, Table 8).

The mortality rate depends on the rate of diameter growth. At a high rate of diameter growth, the mortality is approximately equal to the constant, D. Mortality rate approaches its maximum value as diameter growth drops to zero. Between zero diameter growth and a high rate of diameter growth, mortality rate decreases exponentially.

In GRO2, trees in the understory will be growing more slowly than those in the overstory, and have higher mortality rates. Fast-growing dominant trees will have the highest survival rate. Undamaged trees generally will have a higher diameter increment than damaged trees; thus, the damaged trees will die at a higher rate.

Coefficients provided with Buchman's expressions (1979) were adjusted so that the more shade-tolerant species had a lower mortality rate at lower levels of diameter increment. Shade-intolerant species had a higher mortality rate at the lower levels of diameter increment. Species intermediate in shade tolerance were not adjusted.

Once the mortality rate is determined for a given tree, a new frequency is computed for that tree by multiplying the current frequency by 1 minus the mortality rate. A new basal area per acre also is computed by multiplying the tree basal area by the newly computed frequency.

We assumed that the higher the site index for a given plot, the higher the maximum basal area that can be supported on that plot. It also is assumed that softwood plots can support higher basal areas than hardwood plots; GRO2 keeps the total basal area per acre from exceeding some maximum value for each sample plot.

Given these conditions, the maximum total basal area per acre that can be supported on a 1-acre sample plot is assumed to follow the relation:

$$LMBA = MBAH + RSBA(MBAS - MBAH) \quad (10)$$

where

LMBA = maximum total basal area (ft^2 per acre),

MBAH = maximum basal area for hardwoods (ft^2 per acre),

MBAS = maximum basal area for softwoods (ft^2 per acre),

and

RSBA = ratio of softwood total basal area to hardwood total basal area per acre.

For hardwoods, the maximum basal area per acre is given by the expression:

$$MBAH = 2.5\ WASI \quad (11)$$

where

WASI = weight-averaged site index (ft at breast height age (Bha) = 50).

For softwoods, the maximum basal area per acre is given by the expression:

$$MBAS = 3.375\ WASI \quad (12)$$

The weight-averaged site index for each sample plot is determined from the expression:

$$WASI = \frac{\sum_{i=1}^{N} Site_i\ BA_i}{\sum_{i=1}^{N} BA_i} \quad (13)$$

where

WASI = weight-averaged site index (ft at Bha = 50),

$SITE_i$ = species site index for the i^{th} sample tree (ft at Bha = 50),

BA_i = basal area per acre contributed by the i^{th} sample tree (tree basal area x frequency),

and

N = number of sample trees (not the frequency) on the sample plot.

Substituting for MBAH and MBAS in expression (10) yields:

$$LMBA = 2.5\ WASI\ (1 - RSBA) + 3.375\ RSBA\ WASI \quad (14)$$

Expression (14) is used in GRO2 to determine the maximum allowable total local basal area per acre for a given sample plot.

After the number of simulator trees is reduced through mortality, the total basal area per acre is computed and compared with the maximum allowable for each plot. If the total exceeds the maximum, the plot reenters the mortality subprogram; otherwise, no more mortality occurs on the plot for the current growing season.

Determining Regeneration

New trees are brought into the model in proportion to the basal area of existing species. This simple model of regeneration ignores the many complexities observed in natural regeneration; however, it does provide for ingrowth on the sample plots. For the length of simulation that we envisioned, the species composition and timing of regeneration are of little consequence. To focus on the simulation of regeneration, a more complex model would be needed.

Determining the number of new trees to enter. Only species currently existing on a sample plot are regenerated on that plot. Trees are entered into the 1-inch d.b.h. class at a fixed diameter of 0.5 inch at breast height outside bark, a height of 8.5 feet, and an overtopped crown class.

To determine how many trees to enter on a sample plot, GRO2 examines the total basal area per acre in the 1-inch diameter class (0.50 to 1.49 inches) at the end of each growing season. GRO2 maintains between 1.84 and 5.0 ft^2 basal area per acre in the 1-inch diameter class.

When regeneration occurs, a tree is created for each species existing on the plot. The basal area per acre associated with each new tree is computed from the expression:

$$BA_i = PROBA_j\,(MXBA1 - TOTBA1) \qquad (15)$$

where

BA_i = basal area per acre associated with the i^{th} new tree (ft^2 per acre),

$PROBA_j$ = proportion of total basal area per acre contributed by the j^{th} species on this plot,

MXBA1 = maximum basal area assigned to 1-inch d.b.h. class (ft^2 per acre),

and

TOTBA1 = total basal area per acre in 1-inch class (ft^2 per acre).

The frequency associated with each new tree is given by the expression:

$$FREQ_i = BA_i/TBA_i \qquad (16)$$

where

$FREQ_i$ = frequency associated with i^{th} new tree (trees per acre),

and

TBA_i = tree basal area of i^{th} new tree (ft^2 per acre).

The GRO2 model allows regeneration only when the basal area of the sapling crop in the 1-inch diameter class falls below some arbitrary value (1.84 ft^2). If GRO2 allowed regeneration to occur annually, the number of trees would increase rapidly with little observable impact on the growth characteristics of the larger trees, but with a marked impact on the model's run-time performance.

In practice, the number of new trees entering a simulation usually is small (though the associated frequency may seem large). The reason for this is that mortality of trees in the 1-inch d.b.h. class is balanced by basal-area growth of survivors, which keeps the basal area above the level for entering new trees. Also, trees in this diameter class generally are slow to grow out of it.

Updating Crown Class

At the end of each simulated growing season, a new crown class is selected for each sample tree on each plot. The selected crown class may be the same or different from the prior one. The probability of a sample tree being assigned a given crown class depends on its relative height (Fig. 1).

At the end of each growing season, GRO2 computes a new canopy height for each sample plot. Once the canopy height is known for a plot, the relative height of each tree is determined from the ratio of sample tree height to canopy height.

Sample trees are assigned to one of 16 relative height classes ranging from 0 to 1.5 in steps of 0.1. A discrete probability distribution based on Figure 1 is included in GRO2 for each of the relative height classes. The distribution gives the probability that a tree will be assigned to a given crown class.

A random number between 0 and 1 is selected by GRO2. This number is matched to the cumulative

distribution function for the relative height class, and an appropriate crown class is selected for the sample tree under consideration. The process of selecting crown classes continues until all sample trees on all sample plots have been assigned a crown class.

The possibility of changing crown classes each year is not as unrealistic as it may sound at first. Trees that are at the extremes of relative height, either high or low, have a high probability in GRO2 of remaining in the same crown class from year to year. When changes do occur, it is most often to an adjacent crown class. Rarely does a tree shift two classes in one year. However, because of the relative height probability distribution, this outcome is possible. Five trees on one plot from the 1983 Vermont forest inventory were monitored for changes in crown class for a simulation period of 51 years (Table 3).

The stochastic treatment of crown class serves two functions. First, it models the random variation in radial increment. If radial growth of a particular tree is defined as the sum of a constant and a random term, we have said in GRO2 that radial increment changes "as if" the crown class were changing.

The second function deals with changes in canopy height and relative heights of sample trees. These changes may be the result of height growth, thinning, or harvesting. But they alert the model that a tree's competitive position and, therefore, its radial growth may change.

Calibration Data

The algorithms in GRO2 illustrate how the model simulates change in a forest stand. Although presented independently of DATA2 and YIELD, the three computer programs complement each other in VWRAP by allowing input of plot data, processing of that data, and output of stand summary tables. However, GRO2 can be used separately as a subprogram if desired.

In addition to generating the logic and FORTRAN code, the development of GRO2 also required the specification of the functional relationships that described the dynamics of forest stands, and the empirical estimation of the parameters of those functions. The calibration of the model was accomplished with a set of data from 530 trees. There were 432 growth-rate trees (Table 4) and 309 site-index trees, with 211 trees used in both capacities. These data were collected by the Service Foresters in the Vermont Department of Forests, Parks, and Recreation. Because of the relatively small sample size, a probability sample was not attempted. Instead, a matrix of species (10) by crown class (4) was constructed and sample trees were selected from around Vermont to fill each cell. The trees were selected arbitrarily from forest stands with a basal area of 100 ft^2 per acre or more. Only live, nondiseased trees were selected. The key data collected for each tree included: species; crown class; increment core at breast height through the pith; total height; d.b.h.; and site index.

Table 3.—Results of changes in crown class for five trees for a 51-year simulation using GRO2

Tree number	Species	Initial crown class	Final crown class	Total number of crown class changes in 51 years	Total number of crown class changes exceeding 1 class[a]
1	Yellow birch	4	2	22	4
2	Eastern hemlock	2	2	27	7
3	Sugar maple	2	1	7	0
4	Sugar maple	3	1	24	2
5	Sugar maple	2	1	5	0

[a] No change in excess of two classes occurred.

Table 4.—Number of growth-rate trees, by crown class

Species	Crown class				
	Dominant	Codominant	Intermediate	Overtopped	Total
American beech	13	12	12	11	48
Northern red oak	14	16	11	12	53
Red maple	13	12	12	10	47
Sugar maple	16	15	13	15	59
White ash	15	13	10	9	47
White birch	10	9	9	7	35
Yellow birch	8	13	8	9	38
Eastern hemlock	9	10	8	10	37
Eastern white pine	14	10	9	9	42
Red spruce	6	7	6	7	26
Total	118	117	98	99	432

The increment cores for growth-rate and site-index trees were analyzed in the laboratory. Radial increment was measured to the nearest 0.1 mm for the most recent 12 growth rings. The age at breast height, from a ring count, and the distance from the cambium to pith also were recorded. Each core was analyzed twice to reduce measurement errors.

The data were analyzed statistically to obtain the annual radial-increment coefficients in the Appendix (Table 6). The growth-rate trees were used to obtain the coefficients on sites exceeding 100 ft^2 basal area per acre. The site-index trees were used to obtain the radial-growth coefficients on sites with less than 40 ft^2 basal area per acre. These trees were either in the dominant or codominant crown class, free from disease, damage, and suppression, and between 30 and 100 years at breast height. In other words, they represented the best expression of growth potential on the site for the species.

Sample Output From GRO2

The GRO2 model has been tested for soundness of its results; that is, for the stands in which it has been used to simulate change, the results seem reasonable. A systematic program of testing using actual stand growth data is planned.

The data summaries available from GRO2 include a Stand Table, Basal Area Table, Biomass Table (dry tons per acre), Biomass Value Table, Net Biomass Table (net of sawlogs), Net Biomass Value Table, Sawtimber Volume Table, Sawtimber Value Table, Sawtimber Stand Table, Sawtimber Basal Area Table, and D.b.h./Stems per acre Histogram. All or any combination of tables can be printed. Biomass weight is estimated by equations developed by Monteith (1979).

As an example, 11 plots were taken in a typical mixed stand in the Sugar Maple-Beech-Yellow Birch forest type in northern Vermont. Table 5 is the stand table from GRO2 at the time of data collection, November, 1982. The stand is pole- to small sawtimber-sized, with 97.3 ft^2 basal area per acre. It has not been managed actively, though merchantable timber has been cut in the past.

Table 5.—Beginning stand table produced by GRO2 for a northern hardwood stand in Vermont

D.b.h. class	Sugar maple	Yellow birch	Black cherry	American beech	Red maple	Red spruce	Total
Inches	*No. stems/acre*						
3	49.5	24.7	0.0	0.0	0.0	0.0	74.2
4	12.2	12.2	0.0	0.0	0.0	0.0	24.4
5	21.6	5.9	0.0	11.4	5.9	6.2	51.1
6	22.4	5.5	0.0	4.8	0.0	5.3	38.0
7	3.0	7.1	3.8	0.0	13.6	0.0	27.5
8	0.0	5.1	0.0	0.0	2.5	0.0	7.6
9	21.5	3.9	4.1	4.1	2.2	0.0	35.7
10	6.6	1.8	0.0	4.7	3.1	0.0	16.3
11	4.3	1.3	1.4	5.5	2.9	2.7	18.0
12	5.7	2.4	1.2	0.0	2.3	0.0	11.7
13	1.0	0.0	1.0	0.0	2.0	0.0	4.1
14	0.0	0.9	0.9	1.7	0.9	0.0	4.3
15	0.0	0.7	0.0	0.0	0.7	0.0	1.4
16	0.7	0.0	0.0	0.7	0.6	0.0	2.0
17	0.6	0.6	0.0	1.8	0.0	0.0	3.0
18	1.0	0.0	0.0	0.0	0.5	0.0	1.6
19	0.0	0.0	0.0	0.5	0.0	0.0	0.5
30	0.2	0.0	0.0	0.0	0.0	0.0	0.2
Total	150.3	72.1	12.4	35.1	37.2	14.2	321.3

Using GRO2, the stand growth was simulated for a 25-year period assuming no silvicultural practices or harvesting. Figures 2 through 4 show some of the data summaries that can be made from GRO2 output. Figure 2 shows how species composition changed over the 25-year period. Figure 3 shows the trend in sawtimber volume by species; Figure 4 shows the change in the diameter distribution of the stand from 1982 to 2007. In addition, total biomass of the stand increased from 63.1 dry tons per acre in 1982 to 89.1 tons in 2007.

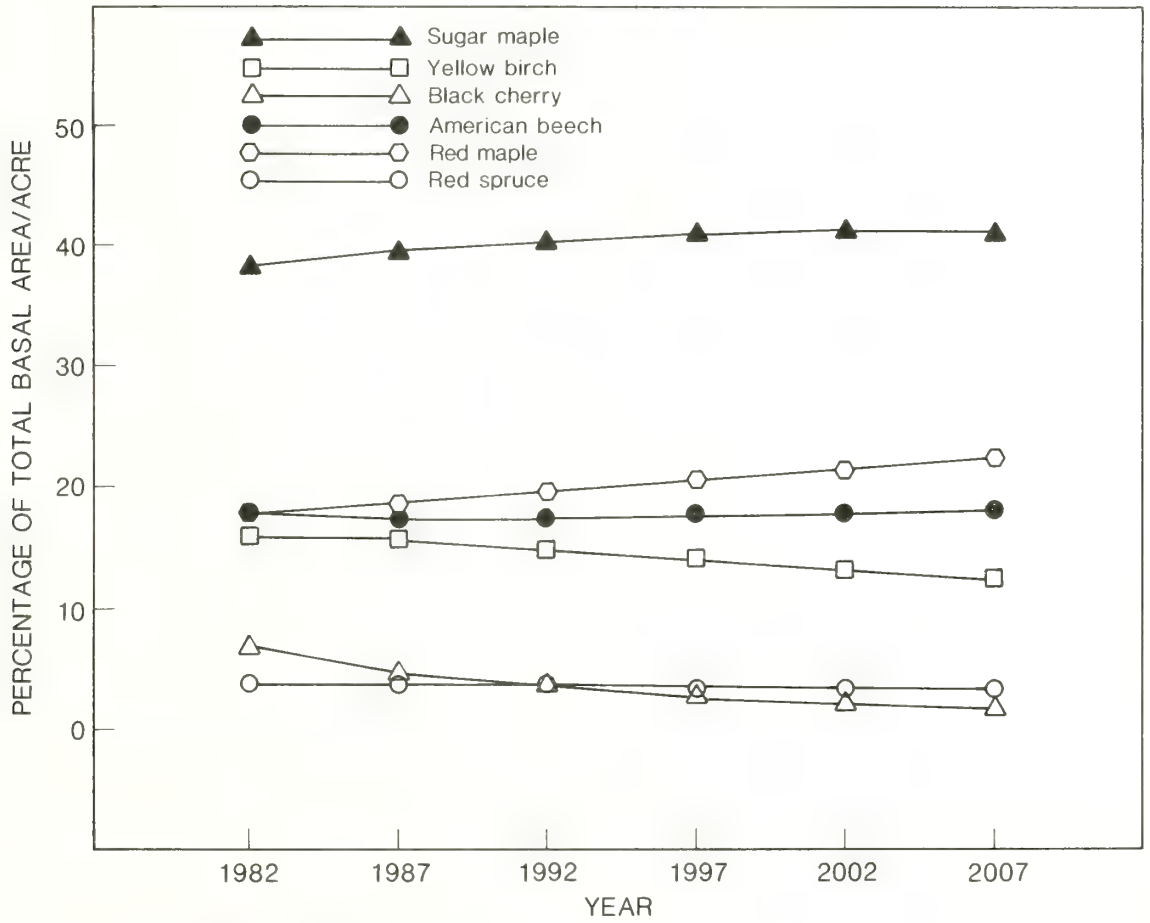

Figure 2.—Simulated changes in basal area in a northern hardwood stand in Vermont for a 25-year period.

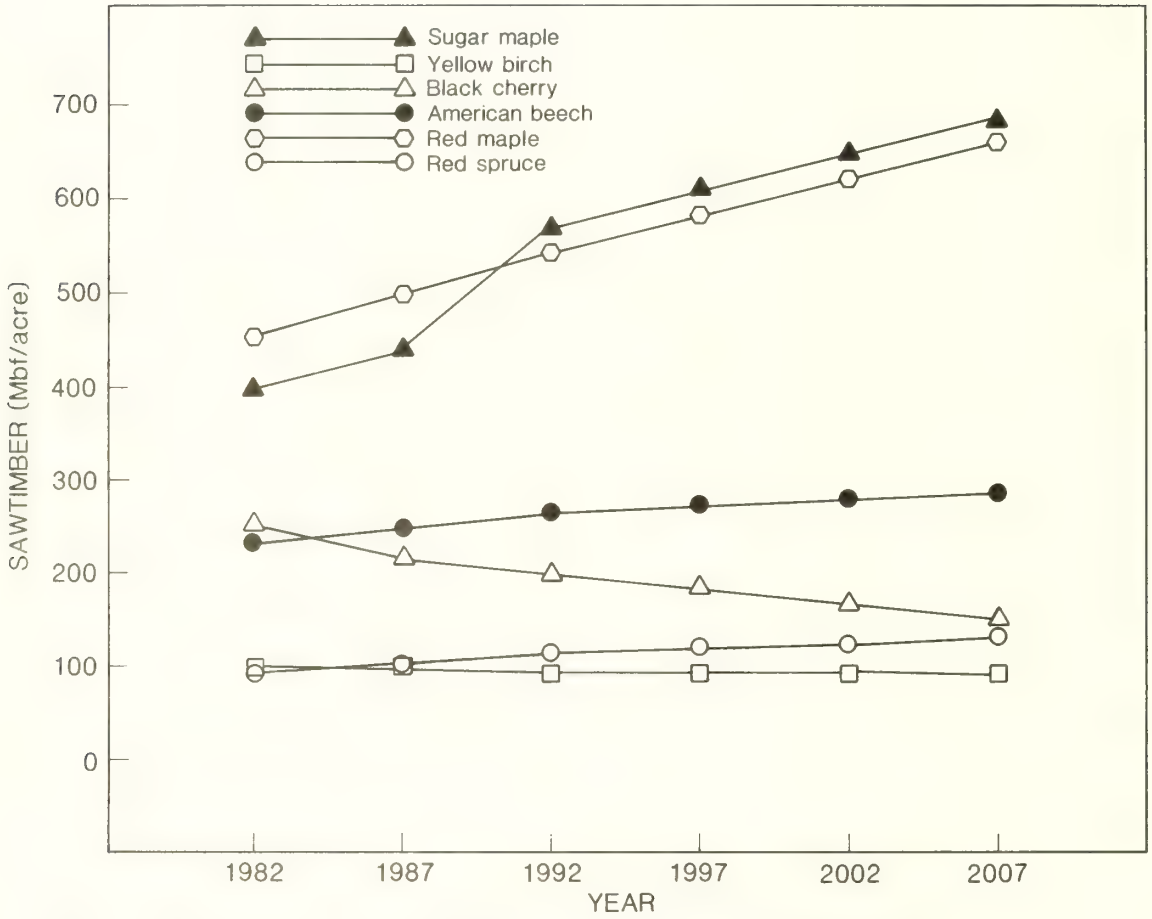

Figure 3.—Simulated changes in sawtimber volume in a northern hardwood stand in Vermont for a 25-year period.

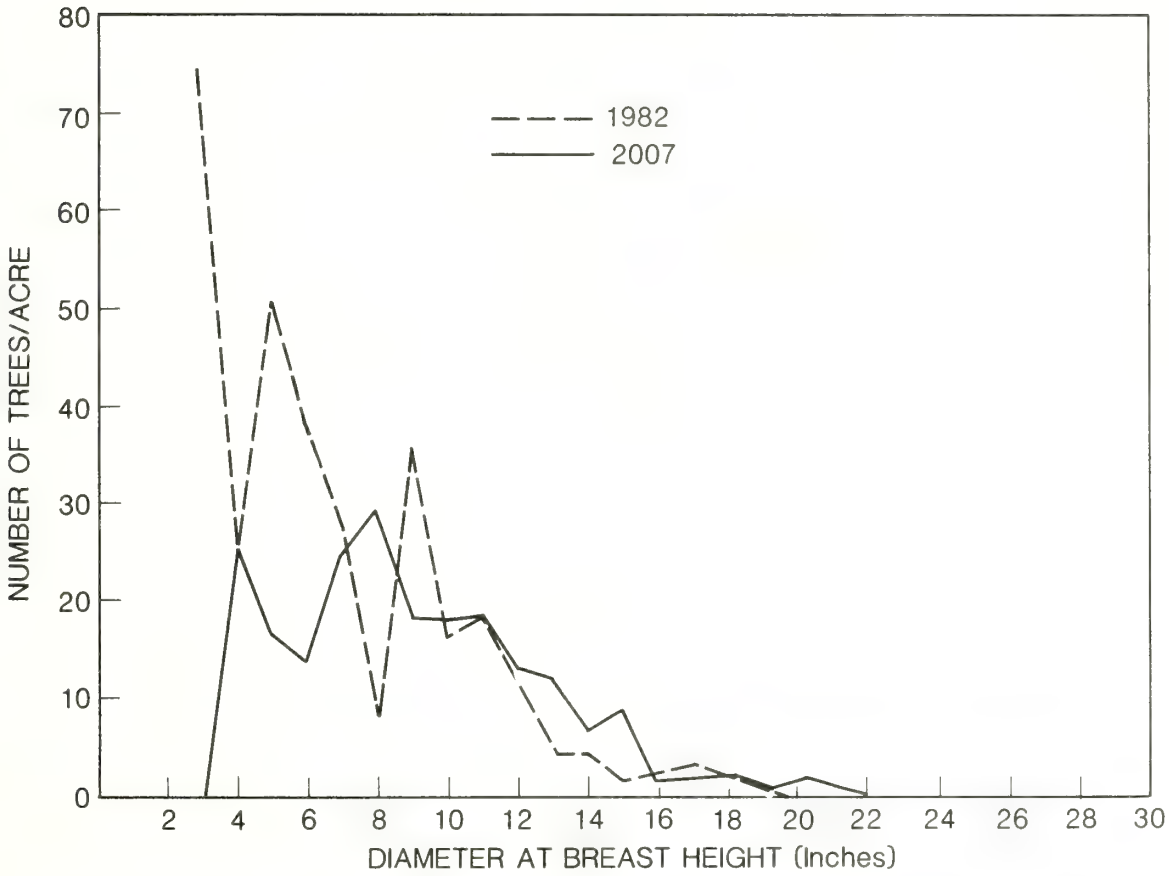

Figure 4.—Diameter (d.b.h.) distribution for a northern hardwood stand in Vermont for 1982 and 2007.

Conclusion

We believe that in its intended application, as a growth simulator in VWRAP, GRO2 is useful for the kinds of forest management decisions made by landowners and managers in Vermont. It can give landowners and managers a reasonable view of the future consequences of their potential management decisions. Together with an economic analysis, GRO2 should improve the decision-making process and could lead to more acreage of forest land under management.

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Acknowledgment

This study was the result of cooperation between the Northeastern Forest Experiment Station; Burlington (VT) Electric Department; Vermont Department of Forests, Parks, and Recreation; and Extension Service, University of Vermont. The contributions of the following people to the project are gratefully acknowledged: William Kropelin, Brian Stone, Thomas McEvoy, Harold Remington, and the Vermont Service Foresters.

Appendix

Table 6.—Annual radial-increment coefficients (mm) used in GRO2, by total basal area per acre and crown class

Species	Total basal area/acre									
	> 100 ft²/acre								< 40 ft²/acre	
	Crown class									
	Dominant		Codominant		Intermediate		Overtopped			
	X_0	X_1	X_0	X_1	X_0	X_1	X_0	X_1	X_0	X_1
American beech	1.5977	0.0	1.2967	0.0	0.7367	0.0	0.5345	0.0	0.8776	0.018170
Northern red oak	1.9500	0.0	1.6550	0.0	1.0055	0.0	0.5383	0.0	1.1841	0.021559
Red maple	1.4492	0.0	1.3733	0.0	0.6425	0.0	0.5140	0.0	0.1642	0.033667
Sugar maple	−0.1525	0.02115	1.2167	0.0	0.6338	0.0	0.3420	0.0	0.1117	0.030261
White ash	−0.3110	0.03311	−0.3730	0.02716	0.9100	0.0	0.5378	0.0	1.5380	0.015797
White birch	1.1150	0.0	0.7833	0.0	0.5333	0.0	0.2186	0.0	0.8734	0.022506
Yellow birch	1.5012	0.0	1.0215	0.0	0.4812	0.0	0.3289	0.0	2.1992	0.0
Eastern hemlock	1.3611	0.0	0.7856	0.0	0.7856	0.0	0.1620	0.0	0.1364	0.034360
Eastern white pine	2.9271	0.0	1.7990	0.0	1.1211	0.0	0.1533	0.0	1.0984	0.033930
Red spruce	1.3983	0.0	1.1886	0.0	0.2933	0.0	0.2500	0.0	2.1871	0.0
Other hard-woods	0.3545	0.01997	1.2822	0.0	0.7147	0.0	0.4375	0.0	0.6948	0.025041
Other softwoods	2.1248	0.0	1.2478	0.0	0.8091	0.0	0.1827	0.0	−0.1300	0.046049

Table 7.—Values of time height constant (THTC) and maximum height (TMXH), by species and site index

Species	Site-index class													
	40		50		60		70		80		90		100	
	THTC	*TMXH*	*THTC*	*TMXH*	*THTC*	*TMXH*	*THTC*	*TMXH*	*THTC*	*TMXH*	*THTC*	*TMXH*	*THTC*	*TMXH*
American beech	796.88	588.16	161.13	175.07	88.38	132.96	63.09	124.17	47.61	120.64	39.75	123.96	60.35	174.04
Northern red oak	205.08	168.58	78.71	101.27	57.32	99.87	43.12	99.92	33.59	102.01	19.73	97.36	43.36	144.05
Red maple	115.86	105.63	91.60	112.66	86.13	130.54	71.97	135.29	64.55	144.56	57.23	151.27	52.25	159.53
Sugar maple	53.71	63.11	53.76	79.65	53.71	96.12	53.76	112.68	53.76	129.20	53.76	145.72	56.40	166.93
White ash	38.09	53.06	38.04	66.71	38.04	80.38	38.04	94.06	38.04	107.73	38.04	121.40	39.65	137.77
White birch	32.50	50.94	33.11	64.19	33.57	77.47	33.84	90.71	34.08	103.98	34.25	117.24	37.99	136.63
Yellow birch	45.12	57.50	45.17	72.46	45.12	87.36	45.12	102.28	45.12	117.22	45.12	132.14	48.95	153.73
Eastern hemlock	33.11	50.07	50.24	76.69	47.75	90.01	49.31	107.30	53.61	129.00	60.45	156.45	52.25	159.53
Eastern white pine	141.60	123.82	98.83	119.10	80.08	124.01	70.61	133.57	73.63	157.69	60.45	156.45	47.56	151.30
Red spruce	33.11	50.07	50.24	76.69	47.75	90.01	46.09	103.44	56.98	133.75	60.45	156.45	47.59	151.30

Table 8.—Tree mortality coefficients used in GRO2

Species	Coefficient			
	A	B	C	D
American basswood	3.18	25.3602	0.8900	0.00317
American elm	1.9889	44.5414	1.0965	0.00899
Bigtooth aspen	0.8805	56.5925	1.2154	0.01288
Black ash	1.70	13.3384	0.7500	0.00018
Hickory	2.75	63.4946	1.0498	0.00134
Paper birch	1.52	21.50	0.8000	0.00029
Quaking aspen	1.2199	693.5903	2.0753	0.02384
Red maple	2.68	53.5938	1.0500	0.00494
Red oak	2.3092	6,999.820	2.6615	0.00468
Sugar maple	3.1831	82.5642	1.3605	0.00405
White ash	1.7821	232.3075	1.7267	0.00222
White oak	2.89	95.6369	1.4517	0.00188
Yellow birch	2.6705	63.1477	1.3819	0.00382
Balsam fir	2.92	29.5772	0.9500	0.00265
Black spruce	2.8774	432.9522	1.8576	0.00235
Eastern hemlock	2.8233	89.5603	1.0966	0.00320
Eastern white pine	2.3507	33.6094	1.0088	0.00201
Jack pine	1.2178	149.3669	1.3699	0.00856
Northern white cedar	13.0	1.0	1.0	0.00402
Red pine	1.65	17.3086	0.7500	0.00042
Tamarack	1.35	30.0	1.0	0.01334
White spruce	2.8806	30.7737	1.2309	0.00396
Other softwoods	2.3507	33.6094	1.0088	0.00201
Other hardwoods	2.2339	29.6290	1.3427	0.00748

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GRO2 is an individual tree, distance-independent simulation model for predicting tree and stand growth over time. It performs five major functions during each run: (1) updates diameter at breast height, (2) updates total height, (3) estimates mortality, (4) determines regeneration, and (5) updates crown class.

ODC 547:564(743)

Keywords: Forest growth; mortality; regeneration; volume estimation (stands); volume increment (stands); site index; crown class

* U.S. GOVERNMENT PRINTING OFFICE: 1985-505-028:20018

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United States
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Research Paper
NE-571

1985

Thinning Increases Growth of 60-Year-Old Cherry-Maple Stands in West Virginia

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Abstract

In north-central West Virginia, previously unmanaged, 60-year-old cherry-maple stands were thinned to 60 percent relative stand density. Thinning reduced mortality, redistributed growth onto fewer, larger stems, and increased individual tree growth. Five-year periodic basal area growth per acre was 1.2 times greater in thinned stands than in unthinned stands. Periodic basal-area growth of individual trees was greater in thinned stands than in controls: 3.0 times for all stems and 1.3 times for dominants and codominants. Relative stand density in the thinned stands increased 1.6 percent annually.

Introduction

The Middle Mountain area on the Monongahela National Forest in north-central West Virginia supports well-stocked cherry-maple stands similar to those found in Allegheny hardwood forests of northwestern Pennsylvania. This area is approaching the southern limit of the most productive natural range of black cherry. There are about 125,000 acres of commercial forest in the Middle Mountain area, most of which is in even-aged cherry-maple stands 60 to 80 years old (Figure 1). Thinnings are now becoming economically feasible in many of these stands. An important question is "Will these unmanaged, even-aged stands respond to thinning at ages 60 years or greater?" In this paper, 5-year growth in thinned stands is compared with that of unthinned stands.

Figure 1.—Typical 60-year-old cherry-maple stand before thinning.

Study

Two tracts, each about 5 acres in size, were thinned to 60 percent relative stand density (Marquis et al. 1984) to determine the amount of wood products that could be produced from thinning 60-year-old cherry-maple stands on Middle Mountain. One tract was thinned in the fall of 1976 and the other was thinned in the spring and summer of 1977 (Figure 2). Detailed product yield data were collected, but no effort was made to document the residual stand growth.

In the spring of 1979, four study plots, each 1/4-acre in size, were established in each thinned tract. Two additional study plots, each one-quarter acre in size, were established in uncut areas close to each thinned tract. On each of the 12 plots, all trees at least 1.0 inch in d.b.h. were permanently marked with galvanized wires and brass tags (Lamson and Rosier 1984). Diameter at breast height (d.b.h.), species, and crown class of each tagged tree were recorded in April 1979 before that year's growth had commenced.

Figure 2.—Typical cherry-maple stand after thinning. Tree being measured is 9.0 inches d.b.h.

In the fall of 1983, 5 growing seasons later, the plots were again inventoried. The d.b.h. of each live tagged tree was measured at the same height that was used in 1979. Ingrowth and mortality were recorded, as well as the crown class of live trees over 1.0 inches d.b.h. If we assume that diameter growth had ceased by the time thinning was completed in the second area in the summer of 1977, these data represent growth for the 2nd through 6th and 3rd through 7th growing seasons after thinning. One control plot was vandalized and dropped from the study, leaving a total of 11 plots.

In April 1979, when the study plots were installed, the control areas averaged 735 stems per acre, 155.6 square feet per acre (1.0+ inch d.b.h.), 2,977 cubic feet per acre (5.0+ inch d.b.h.), 8,828 board feet per acre (11.0+ inch d.b.h.) and 105 percent relative stand density (1.0+ inch d.b.h.). The thinned stands averaged 407 stems per acre, 104.2 square feet per acre, 2,041 cubic feet per acre, 7,862 board feet per acre, and 66 percent relative stand density (Table 1).

Assuming that the control and thinned stands were similar before treatment, thinning removed mostly poletimber (5.0 to 10.9 inches d.b.h.). When this study was installed, basal area per acre of stems 1.0 to 4.9 inches d.b.h. and stems 11.0+ inches d.b.h. were similar for the control and thinned stands. However, basal area of poletimber in the thinned stands was only 32.9 square feet per acre, while in the control stands, poletimber basal area averaged 74.2 square feet per acre. This follows the guidelines for thinning Allegheny hardwood stands (Marquis et al. 1984), in which commercial thinnings concentrate the cut in trees of intermediate and weak codominant crown class to redistribute stand growth onto the best codominant trees.

Table 1. Stand data at the time study plots were installed and 5 growing seasons later.

	Thinned				Control			
	1.0–4.9	5.0–10.9	11.0+	Total	1.0–4.9	5.0–10.9	11.0+	Total
April 1979								
No./acre	258	92	57	407	444	229	62	735
BA/acre	13.4	32.9	57.9	104.2	17.4	74.2	64.0	155.6
Cu.ft./acre	—	613	1,428	2,041	—	1,349	1,628	2,977
Bd.ft./acre	—	—	7,862	7,862	—	—	8,828	8,828
RSD	15	25	26	66	20	56	29	105
September 1983								
No./acre	244	99	74	417	375	211	71	657
BA/acre	12.2	30.4	78.4	121.0	14.1	71.3	78	163.4
Cu.ft./acre	—	576	1,961	2,537	—	1,308	1,907	3,215
Bd.ft./acre	—	—	10,817	10,817	—	—	11,358	11,358
RSD	17	29	28	74	17	57	32	106

Basal area = Square feet of basal area of stems 1.0+ inch d.b.h.
Cu. ft. vol. = Cubic foot volume to 4 inches d.i.b. of stems 5.0+ inches d.b.h.
Bd. ft. vol. + International 1/4-inch board-foot volume to 8 inches d.i.b. of stems 11.0+ inches d.b.h.
RSD = Relative stand density, percent.

Results

Stand Growth

All trees. Thinning increased the per-acre growth (Table 2). Total basal area per acre of all trees at least 1.0 inch in d.b.h. was greater in the control stands than in the thinned stands. However, basal-area growth for the 5-year period averaged 16.8 square feet per acre in thinned stands and only 7.8 square feet per acre in the control stands; an increase of 2.2 times. Similarly, cubic-foot volume growth of trees at least 5.0 inches d.b.h. for the 5-year measurement period was 496 cubic feet per acre in the thinned stands and only 238 cubic feet per acre in the control stands; an increase of 2.1 times due to thinning.

Board-foot volume growth of those trees at least 11.0 inches in d.b.h. for the 5-year period averaged 2,955 board feet per acre in the thinned stands and 2,530 board feet per acre in the control stands, which is an increase of 1.2 times due to thinning.

Dominant and codominant trees. Dominant and codominant trees are the most important component of even-aged stands because these generate most of the revenue at harvest. Thinning also increased the per acre growth of trees that were dominant or codominant in 1983 (Table 2). It is interesting that the number of dominant and codominant stems per acre was about the same in thinned stands (109) and in the control stands (112). However, the 5-year basal area

Table 2. Five-year stand growth.

	Thinned			Control			5-Year Growth Ratio Thinned: Control
	4/79	9/83	5-Year Growth	4/79	9/83	5-Year Growth	
			ALL TREES				
No./acre	407	417		735	657		
BA/acre	104.2	121.0	16.8 (407)	155.6	163.4	7.8 (735)	2.2
Cu.ft./acre	2,041	2,537	496 (173)	2,977	3,215	238 (282)	2.1
Bd.ft./acre	7,862	10,817	2,955 (74)	8,828	11,358	2,530 (71)	1.2
RSD	66	74		105	106		
			DOMINANT AND CODOMINANT TREES				
No./acre	109	109		112	112		
BA/acre	80.6	93.2	12.6 (109)	85.6	95.8	10.2 (112)	1.2
Cu.ft./acre	1,858	2,258	400 (107)	2,027	2,246	219 (110)	1.8
Bd.ft./acre	7,767	10,648	2,881 (72)	8,436	10,740	2,304 (65)	1.3
RSD	43	48		44	48		
			DOMINANT AND CODOMINANT CHERRY TREES				
No./acre	51	51		69	69		
BA/acre	48.1	54.7	6.6 (51)	61.0	67.9	6.9 (69)	1.0
Cu.ft./acre	1,157	1,369	212 (51)	1,482	1,622	140 (69)	1.5
Bd.ft./acre	5,892	7,740	1,848 (47)	6,997	8,691	1,694 (52)	1.1
RSD	20	22		25	27		

Note: Numbers in parentheses refer to number of trees used in calculations.
Number = Number of stems 1.0+ inches d.b.h.
BA = Square feet of basal area of stems 1.0+ inches d.b.h.
Cu.ft. = Cubic-foot volume to 4 inches d.i.b. of stems 5.0+ inches d.b.h.
Bd.ft. = International 1/4 inch board-foot volume to 8 inches d.i.b. of stems 11.0+ inches d.b.h.
RSD = Relative stand density, percent.

growth of dominant and codominant trees averaged 12.6 square feet per acre in the thinned stands and only 10.2 square feet per acre in the control stands. This represents a 20 percent increase due to thinning. In 1983 the total basal area of dominant and codominant stems averaged about the same for thinned and control stands, 93.2 and 95.8 square feet per acre, respectively.

Volume growth for the 5-year period averaged 400 cubic-feet per acre in the thinned stands, and 219 cubic feet per acre in the control stands; an 80 percent increase due to thinning. Sawlog volume growth of dominant and codominant trees averaged 2,881 board feet per acre in the thinned stands and 2,304 board feet per acre in the control stands. Like cubic-foot volume, total board-foot volume per acre was nearly the same for thinned and control stands at the end of the measurement period: 10,648 and 10,740 board feet per acre, respectively.

Dominant and Codominant Black Cherry Trees. The dominant and codominant trees in these stands are primarily a mixture of black cherry, red maple, and sugar maple. Of these species, black cherry is the most valuable. Basal-area growth per acre of dominant and codominant black cherry trees that were dominant or codominant in 1983 was about equal in the thinned and control stands, 6.6 and 6.9 square feet per acre, respectively. Although total basal-area growth per acre was not increased by thinning, the individual trees did respond to thinning. In the thinned stands, 51 dominant and codominant trees grew 6.6 square feet per acre, while in the control stands, 69 trees grew 6.9 square feet per acre.

Both cubic-foot and board-foot volume per acre of dominant and codominant black cherry trees were increased by thinning.

Mortality, Ingrowth and Survivor Growth

All Trees. Mortality was greater in the control than in the thinned stands (Table 3). In both stands, mortality occurred only in the intermediate and overtopped crown classes. When the stand growth from table 2 was adjusted for ingrowth and mortality, the survivor growth was greater in the thinned than in the control stands. Thinning increased per-acre survivor basal area growth 1.2 times, survivor cubic-foot volume growth 1.5 times, and survivor board-foot volume growth 1.1 times (Table 3).

Dominant and codominant trees. There was no mortality or ingrowth of dominant and codominant trees. In other words, no dominant or codominant trees died during the 5-year measurement period and no trees that crossed the 1.0-inch d.b.h. threshold were dominant or codominant. However, a portion of the cubic-foot volume present in 9/83 came from trees that crossed the 5.0-inch d.b.h. threshold, which is defined as cubic-foot volume ingrowth. Similarly, the 9/83 board-foot volume of trees that crossed the 11.0-inch d.b.h. threshold is defined as board-foot volume ingrowth. When stand growth from table 2 was adjusted for ingrowth, thinning increased the survivor growth of dominants and codominants (Table 3). Per-acre survivor basal-area growth was increased 1.2 times, survivor cubic-foot growth was increased 1.8 times, and survivor board-foot growth was increased 1.2 times.

Dominant and codominant black cherry trees. Survivor growth of dominant or codominant black cherry trees was increased by thinning (Table 3). Survivor basal-area growth in the thinned stands averaged 6.6 square feet per acre while in the control it averaged 6.9 square feet per acre. But because there were 69 trees per acre in the control stands and only 51 trees per acre in the thinned stands, individual tree growth was increased 1.3 times by thinning. Similarly, board foot volume growth per acre was only slightly increased by thinning, but individual tree growth was increased 1.4 times. Survivor basal-area growth per acre of thinned stands averaged 1.5 times more than that in the control stands.

Individual Tree Growth

All trees. Diameter growth of all individual trees was increased about 3 times by thinning (Table 4). During the 5-year measurement period, the average d.b.h. increased from 5.5 to 6.1 inches in the thinned stands, while in the control stands it increased from 5.1 to 5.3 inches.

Basal-area growth per tree was increased even more than d.b.h. growth per tree by thinning. In the thinned stands, basal area per tree increased from 23.7 to 29.2 square inches in the 5-year measurement period. Basal area per tree in the control stands increased from 20.4 to 22.1 square inches. This represents an increase due to thinning of 3.2 times. Analysis of variance indicated that individual trees in the thinned stands grew significantly faster than those in the control stands.

Dominant and codominant trees. For the 5-year period, d.b.h. and basal-area growth of individual trees that were dominant or codominant in 1983 was increased about 1.3 times by thinning (Table 4). In the thinned stands, average d.b.h. per tree increased only 0.9 inches, while in the control, average d.b.h. increased only 0.7 inches. Similarly, average basal area per tree increased by 16.5 square inches per tree in the thinned stands, but only 12.9 square inches per tree in the control stands. Analysis of variance indicated that dominant and codominant trees in the thinned stands grew significantly faster than those in the control stands.

Table 3. Mortality, ingrowth, and survivor growth of thinned and unthinned stands.

	Thinned				Control				Survivor growth ratio Thinned: Control
	5-Year stand growth[1]	Mortality[2]	Ingrowth[3]	Survivor growth[4]	5-Year stand growth	Mortality	Ingrowth	Survivor growth	
				ALL TREES					
No./acre	417	– 9	19	389	657	– 85	7	565	
BA/acre	16.8	– 0.6	0.1	17.3	7.8	– 7.3	0.1	15.0	1.2
CF/acre	496	– 3	65	434	238	– 70	10	298	1.5
BF/acre	2,955	0	827	2,128	2,530	0	618	1,912	1.1
				DOMINANT AND CODOMINANT TREES					
No./acre	107	0	0	107	112	0	0	112	
BA/acre	12.6	0	0	12.6	10.2	0	0	10.2	1.2
CF/acre	400	0	0	402	219	0	0	219	1.8
BF/acre	2,881	0	783	2,098	2,304	0	506	1,798	1.2
				DOMINANT AND CODOMINANT BLACK CHERRY TREES					
No./acre	51	0	0	51	69	0	0	69	
BA/acre	6.6	0	0	6.6	6.9	0	0	6.9	1.0
CF/acre	212	0	0	212	140	0	0	140	1.5
BF/acre	1,848	0	388	1,460	1,694	0	300	1,394	1.0

[1] From table 2.
[2] Trees 1.0+ inches d.b.h.
[3] Ingrowth: Number and basal area threshold d.b.h. is 1.0 inch.
Cubic foot threshold d.b.h. is 5.0 inches.
Board foot threshold d.b.h. is 11.0 inches.
[4] Survivor growth = stand growth + mortality-ingrowth, i.e. growth of trees that were alive both in 4/79 and 9/83.

Table 4. Five-year individual tree growth based on plot means[a].

	Thinned			Control			5-Year Growth	
	4/79	9/83	5-Year Growth	4/79	9/83	5-Year Growth	Ratio Thinned: Control	Signifi-cance
ALL TREES								
No. plots	8			3				
D.b.h./tree(in)	5.5	6.1	0.6	5.1	5.3	0.2	3.0	**
BA/tree(in²)	23.7	29.2	5.5	20.4	22.1	1.7	3.2	**
DOMINANT AND CODOMINANT TREES								
No. plots	8			3				
D.b.h./tree(in)	11.2	12.1	0.9	11.4	12.1	0.7	1.3	**
BA/tree(in²)	98.5	115.0	16.5	102.1	115.0	12.9	1.3	**
DOMINANT AND CODOMINANT BLACK CHERRY TREES								
No. plots	8			3				
D.b.h./tree(in)	13.0	13.8	0.8	12.4	13.1	0.7	1.1	*
BA/tree(in²)	132.7	149.6	16.9	120.8	134.8	14.0	1.2	NS

[a] All data are arithmetic means, not quadratic means.
** = Significantly different at 0.01 level, * = significantly different at 0.05 level.
NS = not significantly different.

Dominant and codominant black cherry trees. During the 5-year measurement period, d.b.h. and basal-area growth of individual black cherry trees that were dominant or codominant in 1983 was also increased by thinning (Table 4). Average d.b.h. per tree increased from 13.0 to 13.8 inches in the thinned stands, but only from 12.4 to 13.1 inches in the control stands. Similarly, basal-area growth per tree averaged 16.9 square inches in the thinned stands but only 14.0 square inches in the control stands; an increase of 1.2 times due to thinning. Again, analysis of variance indicated that trees in the thinned stands grew significantly faster than those in the unthinned stands.

Discussion

It is not possible to predict long-term growth and yield of thinned and unthinned cherry-maple stands from the 5-year growth data of this study. However, these data show that trees in these 60-year-old stands did respond to thinning. Mortality was reduced, growth was redistributed onto fewer, larger stems, and individual trees grew faster.

Ingrowth was negligible in both the control and thinned stands during the 5-year measurement period. Table 1 indicates that the total number of stems per acre increased from 407 to 417 in thinned stands during the 5-year period. Ingrowth exceeded mortality by 10 stems per acre. However, in the control stands, the total number of stems per acre fell from 735 to 657—a decrease of 78 trees per acre—during the measurement period. In other words, thinning eliminated mortality during the 5-year measurement period.

Total basal area and cubic-foot volume growth was about 2 times greater in the thinned stands than in the control stands (Table 2) even though the thinned stands had only about two-thirds as many stems per acre as the control stands. At the beginning of the measurement period the average diameter of all trees was 5.5 inches in the thinned stands and 5.1 inches in the control stands (Table 4). This shows that thinning redistributed the total stand growth of the stems 1.0 inch d.b.h. and larger onto fewer, larger stems.

Table 4 shows that individual trees grew faster in the thinned stands than in the control stands. Not only was the absolute diameter and basal area growth greater, but analysis of variance indicated that individual tree growth was significantly greater in the thinned stands than in the control stands.

Relative stand density in the thinned stands increased 8 percent during the 5-year measurement period or 1.6 percent annually. At this rate, relative stand density will reach 90 percent in another 10 years. Current guidelines recommend thinning when the stands exceed 85 percent relative stand density. Therefore, it appears that these stands can be thinned at intervals of 10 to 15 years.

In conclusion, these data indicate that 60-year-old, previously unmanaged even-aged cherry-maple stands will respond to thinning.

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Lamson, Neil I. **Thinning increases growth of 60-year-old cherry-maple stands in West Virginia.** Res. Pap. NE-571. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1985. 8 p.

In north-central West Virginia, previously unmanaged 60-year-old cherry-maple stands were thinned to 60 percent relative stand density. Thinning reduced mortality, redistributed growth onto fewer, larger stems, and increased individual tree growth. Five-year periodic basal-area growth per acre was 1.2 times greater in thinned stands than in unthinned stands. Periodic basal-area growth of individual trees was greater in thinned stands than in controls: 3.0 times for all stems and 1.3 times for dominants and codominants. Relative stand density in the thinned stands increased 1.6 percent annually.

ODC: 242, 561, 562, 176.1

Keywords: Thinning, diameter increment, volume increment, Allegheny hardwoods

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*U.S. GOVERNMENT PRINTING OFFICE: 1985- 505-028:20023

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**Northeastern Forest
Experiment Station**

Research Paper
NE-572

1985

Effect of Acid Mist and Air Pollutants on Yellow-Poplar Seedling Height and Leaf Growth

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Manuscript received for publication 14 May 1985

Abstract

One-year-old yellow-poplar seedlings were treated with acid mist at pH 2.5, 3.5, 4.5, and 5.5 either alone or in combination with 0.1 ppm O_3, SO_2, and NO_2, or NO_2 plus SO_2. After 4 and 8 weeks of treatment, height, leaf area, and leaf and new shoot weight were determined and growth analysis variables calculated. Height, leaf area, and dry weight decreased with increasing acidity in seedlings treated with acid mist alone. Similar, but smaller reductions occurred in seedlings treated with SO_2 and acid mist, but no differences were found in seedlings fumigated with NO_2, NO_2 plus SO_2, or ozone and acid mist. Further studies using different combinations of pollutants and acid mist must be conducted before their apparent interactions can be more accurately assessed.

The Eastern United States has experienced sublethal doses of atmospheric deposition over long periods of time as regional industrialization and urbanization have intensified. Forests are a dominant ecosystem throughout the Northeast and numerous environmental stresses, including air pollution, have determined species succession, establishment, and productivity. Documentation of these atmospheric impacts is limited since the consequences of pollution are usually chronic and subtle, but over time these simple changes are detrimental to forest growth (Dochinger and Calvert 1978).

Yellow-poplar (*Liriodendron tulipifera* L.) is a primary species in 4 forest cover types and a secondary component in 12 other forest communities throughout most of the Eastern United States (Vick 1973). This species is sensitive to photochemical oxidants (ozone) which can effect foliage mottling, premature leaf loss, and reduced growth (Dochinger 1974, Duchelle et al. 1982). Additional biomass responses can also result from ozone fumigation including decreases in leaf-area ratio, net assimilation rate, and shoot height growth rate (Jensen 1973, 1981).

Although no information is available on the interaction of acid rain and gaseous pollutants on yellow-poplar, limited study has yielded some research data on the gaseous precursors of acid precipitation, sulfur dioxide, and nitrogen oxides, in various combinations with ozone. SO_2 and ozone alone did not suppress total shoot elongation of yellow-poplar after a 5-week fumigation period, whereas the combinations of O_3 + SO_2, SO_2 + NO_2, or the three gases significantly inhibited total shoot height and dry weight. Of the pollutant combinations, SO_2 + NO_2 most severely curtailed the rate of height growth (Mahoney et al. 1983). Conversely, treatment with concentrations of O_3 stimulated growth of yellow-poplar seedlings, whereas treatment with ambient levels had no adverse effect (Kress and Skelly 1982). In areas around urban centers and in the vicinity of industrial sites, dominant or codominant yellow-poplar, growing in ambient air composed periodically of elevated concentrations of oxides of nitrogen and sulfur dioxide, produced less radial increment growth during periods of high pollutant concentrations (Stone and Skelly 1974).

This study was designed to quantify the nature and extent of ambient concentrations of NO_2, SO_2, and O_3 in conjunction with acid mist on shoot growth and leaf biomass of yellow-poplar seedlings.

Materials and Methods

Twenty combinations of acid mist and air pollutant treatments were used in this study. As only four treatment chambers were available, five separate experiments were required. In the first experiment, the seedlings were treated with acid mist alone with pH of either 2.5, 3.5, 4.5, or 5.5. In the second experiment, the seedlings were treated with acid mist solution plus 0.1 ppm SO_2; in the third experiment, acid mist solution and 0.1 ppm NO_2; in the fourth experiment, acid mist and 0.1 ppm O_3; and in the fifth experiment, acid mist and 0.1 ppm SO_2 plus 0.1 ppm NO_2.

The fumigation chambers were similar to those described by Heck and others (1968). The Mylar-covered[1] chambers had a single-pass air system and were located in an environmentally controlled room. The average daily temperature was 25°C, and average night temperature was 20°C. Light intensity during the 16-hour photoperiod was approximately 250 $\mu Em^{-2}sec^{-1}$ The air pollutants were added to the charcoal-filtered air stream and were sampled automatically in each chamber at 20-minute intervals. Ozone was sampled with a Dasibi Model 1003-AHO_3 monitor, SO_2 with a Beckman Model 90 A SO_2 monitor, and NO_2 with a Monitor Labs Nitrogen Oxides Analyzer Model 8840. The seedlings were fumigated 4 hours each morning for 5 days a week, and the monitors were calibrated each day the seedlings were fumigated.

The acidified mist solutions were prepared by adding sulfuric acid to distilled water. The final pH of the four solutions was 2.5, 3.5, 4.5, and 5.5. The solutions were applied to the chamber atmospheres with Northern cold water humidifiers (Model 77). Approximately 1,500 ml of solution were added to each chamber during the 4-hour afternoon treatment period, and mist was applied 7 days a week.

The 1-year-old yellow-poplar seedlings in each experiment were selected for uniformity and potted in 15-cm plastic pots in a bog soil-sand mixture. They were immediately placed on benches in the environmentally controlled room that contained the fumigation chambers. When 80 seedling had broken dormancy, 20 seedlings were randomly assigned to each treatment in

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the experiment and treatments started. The seedlings were watered as required and fertilized every 2 weeks with 100 ml of a general purpose fertilizer (Peters soluble fertilizer 20-20-20).

Four weeks after the treatments were started, 10 randomly selected seedlings from each treatment were harvested. The height, number of leaves, midrib length, and new stem and leaf dry weight of each seedling were measured. Dry weight of the leaves and stems was determined by drying them to constant weight at 100°C. Leaf area was calculated from a quadratic equation relating midrib length to area. The remaining 10 seedlings in each treatment were harvested after 8 weeks of fumigation.

After the final harvest, all the data were averaged by harvest date, and the growth analysis variables calculated. The variables calculated were relative growth rate $(\ln(W_2/W_1)/(T_2-T_1))$, relative leaf-area growth rate $(\ln(A_2/A_1)/(T_2-T_1))$, specific leaf area (A/L), leaf-area ratio (A/W), and net assimilation rate $((W_2-W_1)/(A_2-A_1)) * (\ln(A_2/A_1)/(T_2-T_1))$ where W = total new growth weight, A = leaf area, and L = leaf weight (Hunt 1982). The data from the 8-week harvest within each experiment were also analyzed using a one-way ANOVA. No statistical comparisons were made between experiments because the means and variances were nonhomogeneous.

Results and Discussion

When the seedlings were treated only with acid mist, height growth after 8 weeks significantly decreased with a lowering in pH from 5.5 to 2.5 (Table 1). Leaf weight and new stem weight of these seedlings did not significantly change in pH from 5.5 to 3.5 but decreased significantly when the pH decreased from 3.5 to 2.5. Leaf area was also significantly decreased with a reduction in pH from 3.5 to 2.5.

These differences are also reflected in the growth analysis variables (Table 2). Relative growth rate (RGR), net assimilation rate (NAR), and relative leaf-area growth rate (RLAGR) all decreased with an increase in acidity. A small drop in the variables was observed as the pH went from 5.5 to 3.5, but sharper decreases were found as the pH was lowered from 3.5 to 2.5.

The mechanism by which seedling growth was reduced by the acid mist cannot be explained from this experiment. But by examining the growth analysis variables, some possibilities are suggested. The first suggestion is that acid mist reduced leaf growth rate. As leaf area is one of the controlling factors that determines the amount of photosynthate available for growth, this physiological relationship may then be responsible for the diminished growth of plant dry weight. This supposition is supported by the RLAGR data, which show that the seedlings in the pH 2.5 treatment were only adding new leaf area at a rate of one-seventh that of the seedlings in the pH 5.5 or 4.5 treatment. Even through the RLAGR was considerably lower for the seedlings in the pH 2.5 treatment, the amount of dry-weight movement into the leaves was nearly constant in all four treatments. Leaf-weight ratio (L/W) ranged from 0.76 gm/gm for the seedlings treated with pH 2.5 and 4.5 mist to 0.81 gm/gm for the seedlings treated with pH 3.5 mist. The acid mist may have directly reduced the leaf expansion rate by interfering with the rate of cell enlargement during the growth process or cell division in the meristematic regions.

The acid mist apparently reduced the treatment growth rates by indirectly inhibiting the photosynthetic rate. NAR for the seedlings treated with pH 2.5 mist was less than zero. This response implies that more carbohydrate was being used in respiration or repair of injured tissue than was being produced.

This reduction in growth or dry weight production with a decrease in pH is partially supported by other researchers. Irving (1983) reviewed the current literature and concluded that the effects of acidified precipitation on crops seem to be minimal and responses may be either positive or negative. Wedding and others (1979) treated soybean plants with sulfuric-acid mist droplets. They found no visible toxicity symptoms on the plants, and tissue examined with the scanning electron microscope showed no apparent damage due to the mist.

When the seedlings were fumigated with SO_2 in the morning before being treated with acid mist in the afternoon, similar growth patterns to those obtained with acid mist alone were observed, but only leaf area was significantly affected. Height of the seedling decreased with an increase in acidity, while acidity had no affect on leaf dry weight and new stem dry weight until the pH dropped below 3.5. RGR, NAR, LAR, SLA, and RLAGR decreased with increasing acidity with losses in LAR and SLA being greater than those observed with mist alone.

Table 1.—Height, leaf dry weight, new stem dry weight, and leaf area of yellow-poplar seedlings treated with acid mist and/or air pollutants for 8 weeks (mean of 10 seedlings)

Pollutant	Mist	Height	Leaf Dry Wt	New Stem Dry Wt	Leaf Area
	pH	*mm*	*gm*	*gm*	*cm²*
None	5.5	112a	.62a	.13a	198a
	4.5	99a	.72a	.13a	215a
	3.5	87a	.67a	.14a	186a
	2.5	44b	.15b	.05b	50b
SO_2	5.5	104	.90	.20	274a
	4.5	119	.98	.21	293a
	3.5	87	.71	.19	202ab
	2.5	65	.35	.10	78b
NO_2	5.5	213	1.49	.49	608
	4.5	175	1.60	.45	553
	3.5	206	2.03	.52	656
	2.5	175	1.40	.41	513
$SO_2 + NO_2$	5.5	225	1.07	.40	521
	4.5	210	1.19	.43	493
	3.5	148	.78	.25	277
	2.5	171	1.01	.32	315
O_3	5.5	259	.67	.17	292
	4.5	221	.60	.15	231
	3.5	242	1.10	.24	416
	2.5	228	.84	.18	302

Values in the same column for each pollutant followed by the same letter are not significantly different at the 0.05 percent level. (Duncans Multiple Range Test)

Table 2.—Growth analysis variables of yellow-poplar seedlings treated with acid mist and air pollutants

Pollutant	Mist	RGR ($gm\ gm^{-1}\ wk^{-1}$)	NAR ($gm\ cm^{-2}\ wk^{-1}$)	LAR ($cm^2\ gm^{-1}$)	SLA ($cm^2\ gm^{-1}$)	RLAGR ($cm^2\ cm^{-1}\ wk^{-1}$)
	pH					
None	5.5	.371	.0013	280	369	.342
	4.5	.338	.0013	247	326	.350
	3.5	.294	.0012	243	300	.265
	2.5	<0	<0	225	299	.046
SO_2	5.5	.400	.0014	294	355	.323
	4.5	.378	.0015	243	302	.386
	3.5	.252	.0011	275	201	.249
	2.5	.243	.0013	180	232	.217
NO_2	5.5	.109	.0006	198	278	.051
	4.5	.124	.0005	244	333	.159
	3.5	.315	.0001	263	386	.388
	2.5	.359	.0001	297	375	.347
$SO_2 + NO_2$	5.5	.392	.0010	388	484	.348
	4.5	.270	.0008	309	436	.260
	3.5	.189	.0006	270	357	.186
	2.5	.362	.0005	130	308	.221
O_3	5.5	.220	.0005	414	502	.204
	4.5	.174	.0005	360	441	.164
	3.5	.250	.0007	336	395	.233
	2.5	.206	.0006	335	397	.193

When the seedlings were fumigated with NO_2 alone or with SO_2 before the acid mist treatments, no significant differences were observed in any of the four variables measured with a change in pH. Similar results were observed with ozone. The growth analysis variables calculated for the NO_2, NO_2 + SO_2, and O_3 treated plants were variable and showed no consistent trends. For example, whereas RGR and RLAGR tended to increase with acidity in the NO_2 treated seedlings, no distinct trends were observed on the NO_2 plus SO_2 or O_3 fumigated seedlings.

The process by which the air pollutants altered the impact of acid mist observed in the first study is uncertain but may have been partially due to their nutritional contributions. Although no statistical test can be made to compare the seedlings treated wth NO_2 or NO_2 plus SO_2 with the seedlings that did not receive any fumigation, an examination of the data in Table 1 indicates that the seedlings in these treatments had more than twice the leaf area, twice the new stem and leaf dry weight, and were twice as tall as the seedlings that were not fumigated. Even though soluble fertilizer treatment can improve the growth of healthy seedlings, the NO_2 treatment and related gaseous pollutants may have further stimulated growth that could mask the harmful effect of the acid mist.

The results of these studies suggest that yellow-poplar growth decreased with increasing acidity whereas the addition of one or more gaseous pollutants of ozone, nitrogen dioxide, and sulfur dioxide did not cause significant growth reductions with increasing acidity. In an experiment designed to determine if the inclusion of ozone modified the effects of acidity of simulated rain on yield of soybean, Troiano et al. (1983) concluded that soybean mass was only slightly curtailed with increasing acidity in filtered air. However, with unfiltered air (ozone), vegetative mass decreased with increasing acidity. These findings are not in total agreement with our data which indicate that yellow-poplar seedlings receiving ozone and acid mist were not affected whereas seedlings growth was reduced with increasing acidity. Although the procedure and methodology of applying acid rain may be primarily responsible for the experimental discrepancy in growth responses, other environmental and plant characteristics such as dose response, genetical tolerance of host, stages of physiological development, and plant/soil nutrient status may also contribute.

The conclusions of these studies are representative of a laboratory experiment using low gaseous pollutants and acidity dosages to observe their effects on yellow-poplar seedlings. Such extrapolation to forests may be questionable because of probable differences in responses of mature trees subject to variable environmental conditions. Nevertheless, our results indicate that yellow-poplar growth is affected and that the potential for change in forest structure and function may exist. Further study coupling acidity and gaseous pollutant dosages with soil chemistry under field conditions must be conducted to more accurately assess the consequences of atmospheric deposition on early and subsequent growth of forest trees.

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One-year-old yellow-poplar seedlings were treated with acid mist at pH 2.5, 3.5, 4.5, and 5.5 either alone or in combination with 0.1 ppm O_3, SO_2, and NO_2 or NO_2 plus SO_2. After 4 and 8 weeks of treatment, height, leaf area, and leaf and new shoot weight were determined and growth analysis variables calculated. Height, leaf area, and dry weight decreased with increasing acidity in seedlings treated with acid mist alone. Similar, but smaller reductions occurred in seedlings treated with SO_2 and acid mist, but no differences were found in seedlings fumigated with NO_2, NO_2 plus SO_2, or ozone and acid mist. Further studies using different combinations of pollutants and acid mist must be conducted before their apparent interactions can be more accurately assessed.

ODC: 425.1: 111.78: 423 *Liriodendron tulipifera* L.

Keywords: Acid deposition; yellow-poplar seedlings

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Research Paper
NE-573

1986

System 6: A Pricing Strategy for Long Blanks

Hugh W. Reynolds
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Manuscript received for publication 25 April 1985.

Abstract

In System 6, small-diameter, low-grade hardwood timber is used to make blanks in standard sizes. Blanks are made in one thickness and one quality class but in all the standard lengths during each production run. The quantity of blanks per length can be varied, while keeping total yield high, by using proper production control techniques. However, when the percentage of long blanks is increased beyond 15 percent, yields of required blanks will drop—though total yields remain constant—and earnings will be lowered. We describe a procedure that can be used to keep constant or improve earnings when the demand for long blanks exceeds the 15-percent level.

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The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program.

Introduction

In System 6, small-diameter, low-grade hardwood timber is bucked to 6- or 8-foot bolts; each bolt is sawed to two cants; the cants are resawed to boards; the boards are kiln dried; and the kiln-dried boards are made to blanks. The marketing aspects of System 6 and blanks are explained by Reynolds and Gatchell (1979). The System 6 technology is discussed by Reynolds and Gatchell (1982) and a sample plant design is available (Reynolds and Hansen 1984). The economics of using System 6 to make standard-size blanks is explained by Hansen and Reynolds (1984). The derivation of the standard blank sizes is discussed by Araman and others (1982). Operating methods used in the System 6 rough mill to convert the kiln-dried boards to specific quantities of blanks are explained by Reynolds (1984).

We have obtained good yields of blanks with System 6 technology using small-diameter, low-grade hardwoods. Yield is affected by timber quality and by the quantity of blanks needed in each length. The standard blank sizes are shown in Table 1. In general, blank yields are high enough to give good profits when the demand for blanks 50 inches and longer ("long blanks") does not exceed 15 percent of the square-foot area in any

Table 1.—Hardwood blank standard sizes for furniture and cabinet manufacturers, in inches

Nominal thickness	Intended product finish thickness	Actual blank thickness	Blank length											
Clear Quality/26-Inch-Wide Blanks														
5/8	3/8	1/2	13	15	17	18	22	26	31	36	42			
3/4	1/2	5/8	14	17	19	22	25	29	31	35	41	47	58	86
1	3/4	7/8	15	18	21	25	29	33	38	45	50	60	75	100
1-1/4	1	1-1/8	15	18	21	25	29	33	38	45	50	60	75	100
1-1/2	1-1/4	1-3/8	15	18	21	25	28	32	35	40	45	50	60	70	85
2	1-5/8	1-3/4	15	18	21	25	28	32	35	40	45	50	60	70	90
Core Quality/26-Inch-Wide Blanks														
1	3/4	7/8	15	18	21	23	26	29	34	40	50	60	70	95	
1-1/4	1	1-1/8	15	18	21	23	26	29	34	40	50	60	70	85	
Sound Quality/20-Inch-Wide Blanks[a]														
1	3/4	7/8	13	17	19	22	24	27	29	33	44	54	70	80	100
1-1/4	1	1-1/8	15	18	20	23	25	28	33	45	55	65	80	90	100
1-1/2	1-1/4	1-3/8	14	18	21	24	28	31	34	40					
2	1-5/8	1-3/4	12	16	19	21	24	28	30	34					
Sound Quality/20-Inch-Wide Blanks[b]														
1	3/4	7/8	15	18	21	25	29	34	40	50	60	70	95		

[a] For upholstery frames.
[b] For case goods.

one production run. Small-diameter, low-grade timber that does not yield 15-percent long blanks is generally considered too poor to be used in System 6. By contrast, better than average timber can support production runs with demands greater than 15-percent long blanks.

Demand for long blanks, expressed as a percentage of the industry's total demand for blanks, is 21 for solid wood furniture, 28 for veneered furniture, and 13 for kitchen cabinets (Araman et al. 1982). Consequently, some orders for blanks will exceed 15-percent long blanks.

Furniture, kitchen cabinet, and dimension companies that operate their own conventional rough mills do not have trouble making parts shorter than 50 inches. But they must use the highest quality, most expensive lumber to make longer parts. Therefore, these manufacturers would like to buy long blanks for cutup to long parts and make the shorter parts themselves. Blanks producers should be able to sell all the long blanks they can make as a lucrative sideline provided that long blanks are not priced too high.

Operating Procedures

When orders for blanks are received, they are evaluated with program BLANKS (Araman 1983). The results of program BLANKS give the quantities of blanks per length for a given thickness and quality required in a production run. Cutting bills 1 through 4 (Table 2) are typical of bills where the requirements for long blanks are 15 percent or less. With typical System 6 quality timber, the yields are consistently good for these cutting bills. But when the need for long blanks exceeds 15 percent of the total square footage required, as shown in cutting bills 5 through 9, the yields in specified blanks drop. When yields are lower, earnings are lower. Earnings can be kept constant by charging extra (a surcharge) for the long blanks.

In the following section we describe eight System 6 mill operating procedures that can be used to determine the surcharge when more than 15-percent long blanks must be produced. Procedures 1 through 7 resulted in high surcharges and were rejected. Procedure 8 was found acceptable.

Table 2.—4/4 C1F cutting bills, in percent of total square feet

Length class	Cutting bill								
	1	2	3	4	5	6	7	8	9
Long (72–50 inches)	0	5	10	15	20	25	30	35	40
Medium (49–32 inches)	10	15	20	25	30	35	40	45	50
Short (31–21 inches)	50	45	40	35	30	25	20	15	10
Salvage (20 inches or less)	40	35	30	25	20	15	10	5	0

Procedure 1: Normal Operations

When no special modifications to the System 6 operations are made, yields are good for cutting bills 1 through 4. As demand for long blanks increases (cutting bills 5 through 9), yields in the blanks required decrease. The decrease in revenues caused by the decrease in required blanks could be made up by a surcharge for the long blanks. But to keep return on investment (ROI) constant, such surcharges would need to range from 50 to 170 percent of the normal blanks price.

Procedure 2: Two-Blank Quality

In this procedure we sorted System 6 kiln-dried boards into two quality classes. Boards graded No. 3A Common and Better were used to make clear-quality blanks. The remainder was used to make frame-quality blanks. The yield of frame-quality blanks was good (Reynolds and Araman 1983), but the value of frame blanks was considerably lower than clear-one-face (C1F) blanks. Consequently, for cutting bills 5 through 9, the yield of clear blanks from the better boards was not high enough to offset the lower earnings of the frame blanks. Surcharges ranging from 50 to 170 percent of the normal blanks price were needed for the long, clear blanks to bring earnings to the required level.

Procedure 3: Better Cants

Not all small-diameter, low-grade timber suitable for System 6 is of the same quality. Quality varies between sites. Would it be practical to save the cants made from better quality timber to be used when more long blanks are required? Sorting and saving would increase costs and might entice timber managers to charge more for better wood. Using data from a study with black cherry (Reynolds and Hansen, in press), we compared "normal" quality cherry cants with "better" quality cherry cants. We added 15 percent to the cost of better cherry cants. The higher yields of blanks from the better cants using cutting bills 5 through 9 did not offset the higher cant cost. Surcharges for long blanks ranging from 25 to 135 percent were required to bring earnings to the required level.

Procedure 4: Sell Everything

System 6 rough-mill operations are preplanned so that only those blanks required by the cutting bill are made (Reynolds 1984). We can achieve this with "normal" System 6 quality timber when the percentage of long blanks is 15 percent or less. When a cutting bill requires more than 15-percent long blanks, the System 6 techniques require more wood to be processed. One result of this additional processing is blanks in the shorter lengths being produced in excess of the cutting bill requirements. There is no market for these excess blanks at standard prices.

Procedure 4 calls for generating additional demand by discounting the prices of the excess shorter length blanks. By this process, new markets might be found. If we price discount the excess blanks shorter than 50 inches but longer than 20 inches by 25 percent, and price discount the 20-inch and shorter blanks by 50 percent, additional revenues are earned. This extra money does not eliminate the necessity for long-blank surcharges. It does, however, lower the required surcharges to a range of 25 to 50 percent. So the Procedure 4 is better than the first three, but is still not acceptable.

Procedure 5: Chips and Blanks

In Procedure 3, we considered buying better quality timber for use when cutting bills with more than 15-percent long blanks are used. Another way to improve the quality of the kiln-dried boards going through the rough mill is to chip some of the poorest boards as they leave the cant gang resaw. Then more cants will have to be purchased to make enough of the kiln-dried boards to keep the rough mill busy. Sales of the chips from the poorest green boards partially offset the cost of additional cants. Chip values are only about half the cant cost.

This procedure works well if you can buy additional cants at the regular cant price and if the quality of the additional cants is as good as or better than the quality of the regular cants. The better board quality, when 30 percent of the green boards are chipped, results in higher total yields and a higher percentage of long blanks. Cutting bills with up to 25-percent long blanks now can be accommodated without a long-blank surcharge. Surcharges of 33 to 103 percent are required when cutting bills (7 through 9) calling for more than 25-percent long blanks are used.

We then examined three possible combinations of these operating approaches:

Procedure 6: Combination of Procedures 2 and 4

Surprisingly, this combination does not work. Required long-blank surcharges range from 50 to 89 percent. These are greater than the surcharges with Procedure 4 alone.

Procedure 7: Combination of Procedures 3 and 4

This combination also does not work well. Surcharges range from 10 to 45 percent, which is no better than the Procedure 4 alone.

Procedure 8: Combination of Procedures 4 and 5

Improving kiln-dried board quality by chipping the worst of the green boards, buying additional cants at the regular price, selling chips, and selling all of the extra blanks at discount prices will nearly eliminate the need for a long blank surcharge. When 30 percent of the green boards were chipped, or when additional cants were bought at regular prices, or when chips were sold for 50 percent of the cant cost, or when extra blanks less than 50 inches long but more than 20 inches long were sold at 25-percent discount, or when the excess blanks 20 inches and shorter were sold at 50-percent discount, there was no surcharge needed until demand for long blanks rose to 35 percent. A surcharge of 6 percent was needed for cutting bill No. 8 and 18 percent for cutting bill No. 9.

Since this relatively complex procedure is the best one and since the combination of factors can change over wide ranges, we wrote a computer program to assist in determining the surcharge required.

Using Program LOBLS1

Program LOBLS1 is written in BASICA for use on the IBM-PC. The two-diskette model with 256K memory and matrix printer is assumed. To start, we suggest the user format a diskette using the /s option. Then copy the MSDOS diskette files onto this diskette. We used COMMAND.COM, ANSI.SYS, PRINT.COM, ASSIGN.COM, FIND.EXE, and BASICA.COM. Then copy the program listed in the Appendix and save it on this diskette. Now format a second diskette without the /s option. Put the first diskette in drive A and the second diskette in drive B to be used as a scratch file.

The program runs by first calling data from the B drive as the "B:LOBLS1.DAT" file. Since this file will not exist on the B drive diskette for the first run, use the following procedure to set up the file:

- Load the program as "A:LOBLS1.BAS".
- Erase lines 70, 80, and 90 by entering 70-return, 80-return, 90-return.
- Enter RUN and the data input listing on the screen will show all values as zeros.
- Following the prompt line, enter dummy values in all 12 data lines. We suggest using the input data values given in the demonstration printout.
- Enter 13,13 to continue the program.
- When the program is completed, the "B:LOBLS1.DAT" file will have been created.
- Load the program again as "A:LOBLS1.BAS" and lines 70, 80, and 90 will be in the computer memory.

The data used in these demonstration runs were obtained in the black cherry study cited earlier (Reynolds and Hansen, in press). Yield data for the typical quality cherry small-diameter, low-grade timber are shown in Table 3. When 30 percent of the green boards were chipped and additional cants were bought to replace these boards, the yield data are as shown in Table 4.

Table 3.—4/4 C1F long-blank yields from typical quality cherry boards, in percent of blank output

Cutting bill	Yield			Total
	Required blanks	Extra blanks[a]	Excess salvage blanks[b]	
1	44.6	0.0	0.0	44.6
2	45.2	0.0	0.0	45.2
3	45.5	0.0	0.0	45.5
4	46.4	0.0	0.0	46.4
5	37.4	1.3	8.6	47.3
6	40.2	4.5	2.5	47.2
7	34.4	7.2	5.0	46.6
8	30.4	9.2	7.1	46.7
9	27.0	11.3	8.4	46.7

[a] 45 to 21 inches long made but not required.
[b] 18 to 15 inches long made but not required.

Table 4.—4/4 C1F long-blank yields from typical quality cherry boards with 30 percent of the boards chipped, in percent of blank output

Cutting bill[a]	Yield			Total
	Required blanks	Extra blanks[b]	Excess salvage blanks[c]	
5	52.3	0.0	0.0	52.3
6	46.9	3.4	1.9	52.2
7	40.4	6.1	4.5	51.0
8	35.9	8.8	6.6	51.3
9	31.8	11.0	8.4	51.2

[a] Cutting bills 1 through 4 not considered.
[b] 45 to 21 inches long made but not required.
[c] 18 to 15 inches long made but not required.

In demonstration run No. 1, the input data are:

1. $15,840 per shift is required for the cash flow in.
2. When cutting bill No. 8 (Table 4) was used, there was a 35.9-percent yield of required blanks.
3. There was an additional 8.8-percent yield of blanks shorter than 50 inches but longer than 20 inches.
4. There was an additional 6.6-percent yield of blanks 20 inches or shorter.
5. The blanks required by the cutting bill, item 2, will sell for $2.20 per square foot.
6. The extra blanks, item 3, will sell for $1.65 per square foot.
7. The excess salvage blanks, item 4, will sell for $1.10 per square foot.
8. Cutting bill No. 8 calls for 35 percent of all blanks to be 50 inches or longer.
9. Thirty percent of all green boards, the poorest boards, will be sent to the chipper.
10. Cant cost is $180 per thousand board feet (Mbf), free on board (f.o.b.) the System 6 mill, and will not change as more cants are purchased.
11. Chips are worth $13.25 per green ton f.o.b. the System 6 mill.
12. There will be 16.0 Mbf of kiln-dried boards input per shift to the System 6 mill.

In demonstration run No. 1 (Fig. 1) the output values are:

- There were 5,744 square feet of required blanks made (35.9 percent of 16,000 board-foot input), which brought in $12,637 at $2.20 per square foot.

```
                LONG BLANKS SURCHARGE Program 1                  03-07-1985

              Poorest boards chipped; all blanks sold            15:08:33


                              Input Data
  1 Cash flow req'd=    $15,840.00    7 Exc salv blanks price= $ 1.10
  2 Req'd blanks yield=      35.9%    8 Percent long blanks=     35.0%
  3 Extra blanks yield=       8.8%    9 Percent boards chipped= 30.0%
  4 Exc salv blanks yield=    6.6%   10 Cant cost=             $180.00/mbf
  5 Req'd blanks price      $ 2.20   11 Chip price=            $ 13.25/ton
  6 Extra blanks price      $ 1.65   12 Board input per shift    16.00mbf

RUN IDENT:DEMONSTRATION #1

                             Output Values
    Required blanks made=          5,744sqft      Value $12,637
    Extra blanks made=             1,408sqft      Value $ 2,323
    Exc sal blanks made=           1,056sqft      Value $ 1,162
    Chips made=                    12.00tons      Value $   159
    Total cash flow in                                  $16,281
    Additional cants for chips=     4.80mbf       Value $   864
    Cash flow in defecit: earn from surcharge         = $   423
    Long blanks made=            2,010sqft        Value $ 4,423
    Cash flow in req'd from long blanks                 $ 4,846
 Long blanks price=  $ 2.41/sqft     Long blanks surcharge=  $ 0.21/sqft
```

Figure 1.—Program LONG BLANKS SURCHARGE output: Demonstration run No. 1.

- There were 1,408 square feet of extra blanks made (8.8 percent of 16,000 board-foot input), which brought in $2,323 at $1.65 per square foot.

- There were 1,056 square feet of excess salvage blanks made (6.6 percent of 16,000 board-foot input), which brought in $1,162 at $1.10 per square foot.

- Twelve tons of green chips were made (30 percent of 16 Mbf cant input at 2.5 tons per Mbf), which brought in $159 at $13.25 per ton.

- The total of these four items was $16,281.

- An additional 4.8 Mbf of cants at $180 per Mbf had to be purchased to make up for the boards chipped. This cost $864.

- There was $15,417 cash flow in after the additional cants were paid for ($16,281 − $864 = $15,417). The cash flow in required was $15,840 but only $15,417 was brought in, creating a $423 deficit ($15,840 − $15,417 = $423).

- There were 2,010 square feet of long blanks made (35 percent of 5,744 square feet of required blanks) valued at $4,423 (2,010 × $2.20 = $4,422).

- The deficit would have to be made up from the sale of long blanks. A $423 deficit added to the $4,422 long blank value means that $4,846 ($423 + $4,422 = $4,846) needs to be earned by the sale of long blanks.

- The 2,010 square feet of long blanks must be sold for $2.41 per square foot ($4,845/2,010 = $2.41). The long-blanks' surcharge will be $0.21 per square foot.

If no boards had been chipped (Input 9 = 0), the yields would have been 30.4 percent for required blanks (Input 2 = 30.4), 9.2 percent for extra blanks (Input 3 = 9.2), and 7.1 percent for excess salvage blanks (Input 4 = 7.1). These data are shown in Table 3. The surcharge would have been $0.86 per square foot, as shown in demonstration run No. 2 (Fig. 2).

When we use cutting bill 6 and chip 30 percent of the green boards, the yields are 46.9 percent for required blanks, 3.4 percent for extra blanks, and 1.9 percent for excess salvage blanks (Table 4). As shown in demonstration run No. 3 (Fig. 3), there is a negative surcharge. This means that if we charge the regular prices, there will be an additional cash flow in of $1,196.

```
                LONG BLANKS SURCHARGE Program 1              03-07-1985

              Poorest boards chipped; all blanks sold        14:43:52


                              Input Data
  1 Cash flow req'd=    $15,840.00    7 Exc salv blanks price= $ 1.10
  2 Req'd blanks yield=      30.4%    8 Percent long blanks=    35.0%
  3 Extra blanks yield=       9.2%    9 Percent boards chipped=  0.0%
  4 Exc salv blanks yield=    7.1%   10 Cant cost=            $180.00/mbf
  5 Req'd blanks price      $ 2.20   11 Chip price=           $ 13.25/ton
  6 Extra blanks price      $ 1.65   12 Board input per shift   16.00mbf

RUN IDENT:DEMONSTRATION 2

                             Output Values
    Required blanks made=          4,864sqft      Value $10,701
    Extra blanks made=             1,472sqft      Value $ 2,429
    Exc sal blanks made=           1,136sqft      Value $ 1,250
    Chips made=                     0.00tons      Value $     0
    Total cash flow in                                   $14,379
    Additional cants for chips=     0.00mbf       Value $     0
    Cash flow in defecit: earn from surcharge          = $ 1,461
    Long blanks made=              1,702sqft      Value $ 3,745
    Cash flow in req'd from long blanks                  $ 5,206
  Long blanks price=  $ 3.06/sqft     Long blanks surcharge=  $ 0.86/sqft
```

Figure 2.—Program LONG BLANKS SURCHARGE output: Demonstration run No. 2.

```
                LONG BLANKS SURCHARGE Program 1              03-07-1985

              Poorest boards chipped; all blanks sold        15:10:35


                              Input Data
  1 Cash flow req'd=    $15,840.00    7 Exc salv blanks price= $ 1.10
  2 Req'd blanks yield=      46.9%    8 Percent long blanks=    25.0%
  3 Extra blanks yield=       3.4%    9 Percent boards chipped= 30.0%
  4 Exc salv blanks yield=    1.9%   10 Cant cost=            $180.00/mbf
  5 Req'd blanks price      $ 2.20   11 Chip price=           $ 13.25/ton
  6 Extra blanks price      $ 1.65   12 Board input per shift   16.00mbf

RUN IDENT:DEMONSTRATION #3

                             Output Values
    Required blanks made=          7,504sqft      Value $16,509
    Extra blanks made=               544sqft      Value $   898
    Exc sal blanks made=             304sqft      Value $   334
    Chips made=                     12.00tons     Value $   159
    Total cash flow in                                   $17,900
    Additional cants for chips=     4.80mbf       Value $   864
    Cash flow in defecit: earn from surcharge          = $-1,196
    Long blanks made=              1,876sqft      Value $ 4,127
    Cash flow in req'd from long blanks                  $ 2,931
  Long blanks price=  $ 1.56/sqft     Long blanks surcharge=  $-0.64/sqft
```

Figure 3.—Program LONG BLANKS SURCHARGE output: Demonstration run No. 3.

Conclusions

A System 6 blanks manufacturer may need to make large quantities of long blanks. Or an opportunity may arise where a blanks customer is willing to pay a premium price for long blanks. Operating the System 6 business as usual to make the additional long blanks will not be practical. By chipping the poorest boards and by selling the extra short blanks at reduced prices, the making of additional long blanks is practical and could be very lucrative.

When furniture and kitchen cabinet manufacturers are willing to pay surcharges for long blanks, when more cants are available, and when the extra chips and blanks can be sold at reduced prices, the System 6 mill can be operated at greater profit. The System 6 mill manager should have the long-blank surcharge program "LOBLS1.BAS" on the mill IBM-PC so these additional profit opportunities can be seized.

The only other option is to operate the standard mill at a reduced ROI because of lower returns.

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Appendix I Computer Program to Determine Long-Blank Surcharge

```
10 REM This program will calculate the long blanks surcharge needed to meet the
20 REM required cash flow per shift. It is written in BASICA for the IBM PC. It
30 REM saved as "A:LOBLS1.BAS".
40 CLS
50 KEY OFF
60 DEFINT N
70 OPEN "B:LOBLS1.DAT" FOR INPUT AS #1
80 INPUT #1, CFIR,YRB,YEB,YESB,RBP,EBP,ESBP,PLB,PBC,CC,CP,BIPS
90 CLOSE #1
100 N=0
110 ID1$="   1 Cash flow req'd=   $##,###.##"
120 ID2$="   2 Req'd blanks yield=     ##.#%"
130 ID3$="   3 Extra blanks yield=     ##.#%"
140 ID4$="   4 Exc salv blanks yield=  ##.#%"
150 ID5$="   5 Req'd blanks price     $##.##"
160 ID6$="   6 Extra blanks price     $##.##"
170 ID7$="   7 Exc salv blanks price= $##.##"
180 ID8$="   8 Percent long blanks=    ##.#%"
190 ID9$="   9 Percent boards chipped= ##.#%"
200 ID10$="  10 Cant cost=             $###.##/mbf"
210 ID11$="  11 Chip price=           $###.##/ton"
220 ID12$="  12 Board input per shift   ##.##mbf"
230 CLS
240 PRINT: PRINT:
250 PRINT TAB(10) "LONG BLANKS SURCHARGE Program 1": PRINT
260 PRINT "Poorest boards chipped; all blanks sold": PRINT
270 PRINT TAB(15) "Input Data"
280 PRINT USING ID1$; CFIR
290 PRINT USING ID2$; YRB
300 PRINT USING ID3$; YEB
310 PRINT USING ID4$; YESB
320 PRINT USING ID5$; RBP
330 PRINT USING ID6$; EBP
340 PRINT USING ID7$; ESBP
350 PRINT USING ID8$; PLB
360 PRINT USING ID9$; PBC
370 PRINT USING ID10$; CC
380 PRINT USING ID11$; CP
390 PRINT USING ID12$; BIPS
400 PRINT "  13 To solve using this data enter 13,13": PRINT
410 INPUT  "ENTER NUMBER AND DATA VALUE FOR CHANGES"; N,DUM
420 IF N=1 THEN CFIR=DUM ELSE 440
430 GOTO 410
440 IF N=2 THEN YRB=DUM ELSE 460
450 GOTO 410
460 IF N=3 THEN YEB=DUM ELSE 480
470 GOTO 410
480 IF N=4 THEN YESB=DUM ELSE 500
490 GOTO 410
500 IF N=5 THEN RBP=DUM ELSE 520
```

```
510 GOTO 410
520 IF N=6 THEN EBP=DUM ELSE 540
530 GOTO 410
540 IF N=7 THEN ESBP=DUM ELSE 560
550 GOTO 410
560 IF N=8 THEN PLB=DUM ELSE 580
570 GOTO 410
580 IF N=9 THEN PBC=DUM ELSE 600
590 GOTO 410
600 IF N=10 THEN CC=DUM ELSE 620
610 GOTO 410
620 IF N=11 THEN CP=DUM ELSE 640
630 GOTO 410
640 IF N=12 THEN BIPS=DUM ELSE 660
650 GOTO 410
660 IF N>12 GOTO 670
670 OPEN "B:LOBLS1.DAT" FOR OUTPUT AS #1
680 PRINT #1, CFIR;YRB;YEB;YESB;RBP;EBP;ESBP;PLB;PBC;CC;CP;BIPS
690 CLOSE #1
700 RBM=BIPS*1000*(YRB/100)
710 EBM=BIPS*1000*(YEB/100)
720 ESBM=BIPS*1000*(YESB/100)
730 CFIC=CP*2.5*BIPS*(PBC/100)
740 CFIRB=RBM*RBP
750 CFIEB=EBM*EBP
760 CFIESB=ESBM*ESBP
770 TCFI=CFIRB+CFIEB+CFIESB+CFIC
780 CFOAB=BIPS*(PBC/100)*CC
790 CFD=CFIR-TCFI+CFOAB
800 LBM=RBM*(PLB/100)
810 LBV=LBM*RBP
820 CFRLB=LBV+CFD
830 LBP=CFRLB/LBM
840 LBS=LBP-RBP
850 TCM=BIPS*(PBC/100)*2.5
860 ABR=BIPS*(PBC/100)
870 D$=DATE$: T$=TIME$
880 OD1$="     Required blanks made=        ##,###sqft"
890 OD2$="      Value $##,###"
900 OD21$="       Value $##,###"
910 OD4$="     Exc sal blanks made=         ##,###sqft"
920 OD3$="     Extra blanks made=           ##,###sqft"
930 OD5$="     Chips made=                   ##.##tons"
940 OD6$="     Total cash flow in                                    $##,###"
950 OD7$="     Cash flow in defecit: earn from surcharge           = $##,###"
960 OD8$="     Cash flow in req'd from long blanks                   $##,###"
970 OD9$="     Additional cants for chips=   ##.##mbf"
980 OD10$="     Long blanks made=           ##,###sqft"
990 OD11$="  Long blanks price=  $##.##/sqft"
1000 OD12$="     Long blanks surcharge=  $##.##/sqft"
```

```
1010 CLS
1020 PRINT
1030 PRINT TAB(20) "LONG BLANKS SURCHARGE Program 1";
1040 PRINT  TAB(65) D$
1050 PRINT TAB(15) "Poorest boards chipped; all blanks sold";
1060 PRINT TAB(65) T$
1070 PRINT TAB(30) "Input Data"
1080 PRINT USING ID1$; CFIR;
1090 PRINT USING ID7$; ESBP
1100 PRINT USING ID2$; YRB;
1110 PRINT USING ID8$; PLB
1120 PRINT USING ID3$; YEB;
1130 PRINT USING ID9$; PBC
1140 PRINT USING ID4$; YESB;
1150 PRINT USING ID10$; CC
1160 PRINT USING ID5$; RBP;
1170 PRINT USING ID11$; CP
1180 PRINT USING ID6$; EBP;
1190 PRINT USING ID12$; BIPS
1200 INPUT "RUN IDENT:"; RD$
1210 PRINT TAB(30) "Output Values"
1220 PRINT USING OD1$; RBM;
1230 PRINT USING OD2$; CFIRB
1240 PRINT USING OD3$; EBM;
1250 PRINT USING OD2$; CFIEB
1260 PRINT USING OD4$; ESBM;
1270 PRINT USING OD2$; CFIESB
1280 PRINT USING OD5$; TCM;
1290 PRINT USING OD2$; CFIC
1300 PRINT USING OD6$; TCFI
1310 PRINT USING OD9$; ABR;
1320 PRINT USING OD21$; CFOAB
1330 PRINT USING OD7$; CFD
1340 PRINT USING OD10$; LBM;
1350 PRINT USING OD21$; LBV
1360 PRINT USING OD8$; CFRLB
1370 PRINT USING OD11$; LBP;
1380 PRINT USING OD12$; LBS
1390 INPUT "ENTER 1 TO PRINT. ENTER 2 FOR NEW RUN"; NN
1400 IF NN=1 THEN 1420 ELSE 1410
1410 RUN 40
1420 LPRINT: LPRINT: LPRINT
1430 LPRINT TAB(20) "LONG BLANKS SURCHARGE Program 1";
1440 LPRINT  TAB(65) D$
1450 LPRINT
1460 LPRINT TAB(15) "Poorest boards chipped; all blanks sold";
1470 LPRINT TAB(65) T$
1480 LPRINT: LPRINT
1490 LPRINT TAB(30) "Input Data"
1500 LPRINT USING ID1$; CFIR;
```

```
1510 LPRINT USING ID7$; ESBP
1520 LPRINT USING ID2$; YRB;
1530 LPRINT USING ID8$; PLB
1540 LPRINT USING ID3$; YEB;
1550 LPRINT USING ID9$; PBC
1560 LPRINT USING ID4$; YESB;
1570 LPRINT USING ID10$; CC
1580 LPRINT USING ID5$; RBP;
1590 LPRINT USING ID11$; CP
1600 LPRINT USING ID6$; EBP;
1610 LPRINT USING ID12$; BIPS
1620 LPRINT
1630 LPRINT "RUN IDENT:"; RD$
1640 LPRINT
1650 LPRINT TAB(30) "Output Values"
1660 LPRINT USING OD1$; RBM;
1670 LPRINT USING OD2$; CFIRB
1680 LPRINT USING OD3$; EBM;
1690 LPRINT USING OD2$; CFIEB
1700 LPRINT USING OD4$; ESBM;
1710 LPRINT USING OD2$; CFIESB
1720 LPRINT USING OD5$; TCM;
1730 LPRINT USING OD2$; CFIC
1740 LPRINT USING OD6$; TCFI
1750 LPRINT USING OD9$; ABR;
1760 LPRINT USING OD21$; CFOAB
1770 LPRINT USING OD7$; CFD
1780 LPRINT USING OD10$; LBM;
1790 LPRINT USING OD21$; LBV
1800 LPRINT USING OD8$; CFRLB
1810 LPRINT USING OD11$; LBP;
1820 LPRINT USING OD12$; LBS
1830 LPRINT CHR$(12)
1840 GOTO 1390
1850 END
```

Reynolds, Hugh W.; Hansen, Bruce G. **System 6: A pricing strategy for long blanks.** Res. Pap. NE-573. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1986. 14 p.

In System 6, small-diameter, low-grade hardwood timber is used to make blanks in standard sizes. Blanks are made in one thickness and one quality class but in all the standard lengths during each production run. The quantity of blanks per length can be varied, while keeping total yield high, by using proper production control techniques. However, when the percentage of long blanks is increased beyond 15 percent, yields of required blanks will drop—though total yields remain constant—and earnings will be lowered. We describe a procedure that can be used to keep constant or improve earnings when the demand for long blanks exceeds the 15-percent level.

ODC 836.1: 847.1/2

Keywords: Low-grade utilization; hardwood dimension

*U.S. GOVERNMENT PRINTING OFFICE: 1986-605-026:20035

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United States
Department of
Agriculture

Forest Service

**Northeastern Forest
Experiment Station**

Research Paper
NE-574

1986

Making Black Cherry Blanks from System 6

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Manuscript received for publication 16 May 1985.

Abstract

Low-grade, small-diameter black cherry (*Prunus serotina*) timber was used to make System 6 cants. Cherry from the Allegheny National Forest (Ludlow, PA), west-central Pennsylvania (Glen Hope, PA), north-central Pennsylvania (Dushore, PA), western Maryland (Oakland, MD), and the Monongahela National Forest (Middle Mountain, WV) was used. The cants were resawed to 4/4 boards, the boards dried, and blanks were made at the Princeton Laboratory's System 6 pilot plant. By varying the rough mill procedures, differences in board quality and cutting bill requirements were accommodated keeping yields high. The cherry from the Pennsylvania and Maryland sites gave similar yields, while the West Virginia cherry gave 5 percent higher yields. Gum streak was not a problem. Pennsylvania and Maryland cherry gave a 39.0 percent return, and West Virginia cherry gave a 50.3 percent return on a $2.2 million 10-year investment.

Black cherry is a highly sought after furniture wood. We undertook a series of studies to determine if it was not only possible but also economically feasible to use small-diameter, low-grade cherry available from timber harvesting and from silvicultural thinnings in Pennsylvania, Maryland, and West Virginia as raw material for System 6 to make high-quality cherry blanks. The blanks would be used as a substitute for high-quality cherry lumber in the furniture industry.

These studies had three purposes:

- To sample small-diameter, low-grade cherry as System 6 bolts taken from Pennsylvania, Maryland, and West Virginia.
- To demonstrate the flexibility of System 6 in converting the cherry from the different sites to varying quantities of blanks.
- To indicate the economic potential for System 6 mills using cherry from the various sites.

System 6 is used to convert small-diameter, low-grade hardwood timber to standard-size blanks. The blanks are used to make the rough dimension parts required for each piece of furniture. This approach to small timber conversion is explained by Reynolds and Gatchell (1979). The technology of System 6 is also covered by Reynolds and Gatchell (1982). Blanks are panels of defect-free wood that are edge glued to standard widths as developed by Araman and others (1982). The design of System 6 mills is covered by Reynolds and Hansen (1984). The economics of System 6 mills is covered by Hansen and Reynolds (1984). We assume that the reader has a working knowledge of System 6 and blanks.

Procedures

In this paper, we cover research on small-diameter, low-grade cherry from five sites. The small timber was made to bolts, the bolts were sawed to two cants per bolt, and the cants were brought to the System 6 pilot plant for conversion to 4/4 C1F (clear-one-face) blanks. The procedures to convert the timber to blanks are covered in this section. The processing yields per site are covered in the Results section.

Sawmills in the five areas had purchased small-diameter cherry timber that was too small to saw to lumber profitably. This is the timber that must be removed to permit the better trees to grow. The timber was bucked to 6-foot bolt lengths and sawed to two round-edge cants per bolt. Cants were either 3-1/4 or 4 inches thick. The cants were then brought to the Forestry Sciences Laboratory at Princeton, West Virginia, for processing to blanks using System 6.

The cants from each site were processed separately. The cants were resawed to 4/4 boards with an actual thickness of 1-3/16 inches. A board was saved if it had at least one 1-1/2- by 15-inch C1F cutting in it. The boards were immediately sticker stacked in 4-foot-wide by 4-foot-high packages using 1/2-inch-thick stickers on 2-foot centers.

The packages of green boards were put into a predryer for about 21 days lowering the MC (moisture content) to 20 percent. Kiln drying, to bring the final MC to 6 percent, lasted 7 days. Equalizing and conditioning were done during this kiln schedule.

The dried boards were graded using the National Hardwood Lumber Association grade rules for standard hardwood lumber. Board width and length distribution requirements per grade were dropped, but all other criteria were kept. Because of the small size of the System 6 boards, No. 1 Common is the highest possible grade. No boards were rejected. All boards not meeting or exceeding the No. 3A Common grade were tallied as "below grade." Gum streak, when found, was not considered a defect as cherry is graded by standard rules.

The kiln-dried boards were hit-and-miss planed to 1.000 inch thickness. The boards were then gang crosscut to 1, 2, or 3 pieces per board depending on board quality. The pieces without a 1-1/2- by 15-inch cutting were discarded. The good ones were ripped to 1-1/2, 2, 2-1/2, 3, or 3-1/2 inch widths depending on defect location. The pieces were end trimmed to the longest blank length possible. Any remaining edge defects, as in 25 percent of the pieces leaving the end-trim step when the mill is operated well, were ripped out in the last step. The defect-free pieces were edge glued to 26-inch-width panels in each length. Planing to 7/8 of an inch completed the process.

In System 6 processing, choices are made in gang crosscutting to permit optimal efficiencies in making the required number of blanks in the standard lengths. These choices are called "GCL's" for gang crosscut lengths. The C1F blank lengths used were 72, 60, 50, 45, 38, 33, 29, 25, 21, 18, and 15 inches. A research paper (Reynolds 1984) has been written explaining GCL choices. There is no one GCL that will make blanks in all 11 lengths efficiently.

Results

The best black cherry timber is said to grow in northwestern Pennsylvania. We sampled this area's small-diameter, low-grade cherry timber by getting 222 cants from the Allegheny National Forest at Ludlow, Pennsylvania. We also sampled similar sized Pennsylvania cherry timber by getting 210 cants from the west-central part of the state at Glen Hope and 152 cants from the north-central part of the state at Dushore.

In addition, we sampled the small-diameter cherry timber available to western Maryland sawmillers by getting 170 cants from Oakland, Maryland, and 182 cherry cants from the Monongahela National Forest in east-central West Virginia at Middle Mountain. The five cant samples were of similar size and were large enough to determine variations in quality between sites.

The distribution by grade of all dried boards from each site is given in Table 1. The grade distributions of the boards from all three Pennsylvania sites and the Maryland site are very much alike. However, the West Virginia site shows better quality. Experience has shown that small-diameter, low-grade hardwood timber that yields 50 percent or less below-grade dried boards is of high enough quality to be used in System 6. The timber from all sites met this criteria; that from West Virginia exceeded this criteria by a wide margin.

The kiln-dried boards were cut up to C1F pieces. We studied six ways to make 4/4 C1F pieces. Each way to cut up boards to pieces is called a GCL. To select a GCL, the first thing to do is to determine which of the standard blank lengths will be in greatest demand. These target lengths are used to set the saw spacings on the gang crosscut saw. The length choices per GCL are limited to three. Boards can be end trimmed to make one long piece or two medium pieces or three short pieces.

Table 1.—Board grade distribution

(In percent of board feet)

Site	1C	2C	3AC	Below grade	Total
Ludlow, PA	1	23	29	47	100
Glen Hope, PA	3	18	23	56	100
Dushore, PA	3	23	24	50	100
Oakland, MD	2	24	24	50	100
M. Mountain, WV	11	33	23	33	100

However, the GCL's can be made more flexible by changing the sorting criteria used to determine which boards will be gang crosscut to 1, 2, or 3 pieces. The longer the sort criteria, the fewer boards will be selected. For instance, if the criteria used to select boards to be end trimmed to one piece per board were set at 72 inches, few boards would qualify. If this criteria were reduced to 50 inches, then more boards would be selected.

The six GCL target lengths, saw spacings, and sort criteria are outlined in Table 2. The GCL's affect operation of the gang crosscut saw only. All other rough-mill operations proceed the same way regardless of GCL being used.

There were only two different gang saw spacings used—1 set for GCL's 1, 3, and 5 and one set for GCL's 2, 4, and 6. By altering the decision rules as to which saws will be used, we forced more or fewer boards to be gang crosscut to one piece (the "long" boards) or forced more or fewer boards to be gang crosscut to two pieces (the "half" boards). All boards not meeting the "long" or "half" criteria were gang crosscut to three pieces. The exception to this three-piece gang crosscutting was GCL 2 where all boards except the "long" boards were gang crosscut to two pieces.

Table 2. GCL's tested

GCL	Target lengths	Sort criteria	Saw spacing
	Inches	*Inches*	
1	72, 45, 25, 21	Long: 1 1/2 × 72 Half: 1 1/2 × 45	1-2, 25 inch 2-3, 22 inch 3-4, 25 inch
2	72, 38, 33	Long: 1 1/2 × 72 Half: All other boards	1-2, 38 inch 2-4, 39 inch 3 not used
3	72, 45, 25, 21	Long: 1 1/2 × 50 Half: 1 1/2 × 29	1-2, 25 inch 2-3, 22 inch 3-4, 25 inch
4	72, 38, 33, 21, 18	Long: None Half: 1 1/2 × 29	1-2, 33 inch 2-3, 18 inch 3-4, 21 inch
5	45, 25, 21	Long: None Half: 1 1/2 × 29	1-2, 25 inch 2-3, 22 inch 3-4, 25 inch
6	38, 33, 21, 18	Long: None Half: 1 1/2 × 29	1-2, 33 inch 2-3, 18 inch 3-4, 25 inch

The results by GCL are in the form of blank quantity per blank length for each board grade and width. There are four grades of boards in System 6: No. 1 Common, No. 2 Common, No. 3A Common, and below grade. There are two board widths: 3-1/4 and 4 inches since only 3-1/4- and 4-inch cant thicknesses are sawed from the bolt. There are 11 standard blank lengths when 4/4, clear quality blanks are made from 6-foot boards. For each GCL, there is a one-row, eight-column matrix generated giving the total blank yields per board grade and width. The 1 by 8 total yield matrices for each of the six GCL's are shown in Table 3. There is another matrix of 11 rows and 8 columns generated that gives the yield by blank length for each board grade and width. These two matrices constitute a yield table that can be used repeatedly. The 11 by 8 matrices are not reproduced in this report for purposes of brevity.

By multiplying the yield per grade and width (Table 3) as a decimal by the grade/width distribution (Table 4) from the five sites, the yield in square feet of blanks per grade and width of board by site is found. In 4/4 boards, the board footage and square footage are the same. Adding up the square feet yield per board grade and width will give the total yield. The 30 total yield values (5 sites times 6 GCL's per site) are shown in Table 5.

In comparing blank yield values among the various sites (Table 5), it is apparent that yields from four sites—Ludlow, Pennsylvania; Glen Hope, Pennsylvania; Dushore, Pennsylvania; and Oakland, Maryland—are very similar, while the yields from the Middle Mountain, West Virginia, site are higher. Comparing the yield values from Middle Mountain with the other four sites, by GCL's, the Middle Mountain yields range from 2.3 to

Table 3.—Yield values for each GCL per board grade and width

(In square feet of blanks/100 board feet of boards)

Grade width	1C		2C		3AC		Below grade	
	3″	4″	3″	4″	3″	4″	3″	4″
GCL-1	77.8	77.2	48.3	40.3	46.4	55.5	36.0	47.4
GCL-2	64.4	66.3	55.7	59.7	49.1	47.3	34.4	33.2
GCL-3	67.3	60.1	60.4	60.4	51.7	57.3	34.8	34.8
GCL-4	68.5	74.7	52.2	64.4	54.3	60.3	37.5	39.1
GCL-5	76.0	72.7	63.4	64.0	56.7	52.2	35.4	35.4
GCL-6	70.0	76.3	60.5	66.4	58.4	58.0	44.4	37.6

Table 4.—Board grade and width distribution

(In board feet)

Site	1C		2C		3AC		Below grade		Total
	3″	4″	3″	4″	3″	4″	3″	4″	
Ludlow, PA	10	2	110	118	180	110	300	170	1000
Glen Hope, PA	27	4	118	59	168	67	401	155	1000
Dushore, PA	10	22	79	147	110	134	225	273	1000
Oakland, MD	10	10	150	90	170	70	350	150	1000
M. Mountain, WV	30	80	130	200	110	120	190	140	1000

Table 5.—Total 4/4 C1F blank yield values for five cherry sites using six GCL's

(In percent of board feet)

Site	GCL-1	GCL-2	GCL-3	GCL-4	GCL-5	GCL-6
Ludlow, PA	44.3	44.0	46.1	48.2	48.0	51.9
Glen Hope, PA	43.8	42.5	44.2	46.4	46.3	50.6
Dushore, PA	45.8	43.8	46.3	49.1	47.6	51.3
Oakland, MD	43.9	43.7	45.6	47.5	47.7	51.6
M. Mountain, WV	48.1	48.7	51.4	53.5	53.4	56.4

7.2 percent higher with an average of 5.3 percent higher. Comparing the Ludlow, Pennsylvania, site yields, by GCL's, with the other three similar sites—Glenn Hope, Pennsylvania; Dushore, Pennsylvania; and Oakland, Maryland—the Ludlow yields range from 2.1 percent higher to 1.5 percent lower with an average of only 0.6 percent higher. But the C1F blank yields are all uniformly good with one site giving approximately 5 percent higher yields.

Values for total yield are valid in a market sense, only if all blanks can be used no matter how many are made in each length. For instance, one site could have most of the blanks in short lengths while another site could have long and short blanks even though they show an identical total yield value. In the processing control section, we will consider the effect that market demand for specific lengths has on total yield.

Production Control

System 6 rough-mill production runs are preplanned. Three sets of data are needed for the production planning:

- Board-Grade Data: The timber coming from each site or from each cant supplier must be tested to determine the distribution of boards in each grade and width. The data in Table 4 illustrate the board-grade data requirement. All timber or cants coming from the same site or supplier will have a similar grade/width distribution as that found by test. We have shown how these data are obtained.
- GCL Yield Data: These yield data are found when a GCL is tested. In effect, these data are a yield table for that GCL. The yield data will be valid for all boards graded by the standard hardwood grading rules. We have shown how these data are obtained.
- Blank Requirements: The quantity of blanks in each length to be made during the production run.

We know the total industry demand for blanks by length (Araman et al. 1982) for furniture and cabinets. But blanks must be made for individual orders or groups of orders and not for annual demands. In running a furniture or cabinet factory, cutting bills giving the quantity of rough parts by size are made for each production run. The blank maker will be required to supply the blanks necessary for each parts cutting bill. Thus, blank demands, by quantity per length, will vary and the blank maker will make up his own blank cutting bills. Program BLANKS (Araman 1983) is used to determine blank cutting bills and has been programmed for use on the microcomputer (Reynolds and Araman, 1986).

For this paper, we have set up a wide range of blank cutting bills going from one extreme—no long blanks required—to the other extreme—40 percent long blanks required. The nine cutting bills are outlined in Table 6. Long blanks are the limiting factor in the yield per cutting bill as long blanks can be trimmed to make shorter blanks but an excess of shorter blanks must be considered waste.

Table 6.—Cutting bills

(In percent of surface area per length class)

Length class	Cutting bill number								
	1	2	3	4	5	6	7	8	9
Long (72-50)	0	5	10	15	20	25	30	35	40
Medium (49-32)	10	15	20	25	30	35	40	45	50
Short (31-21)	50	45	40	35	30	25	20	15	10
Salvage[a] (20 or less)	40	35	30	25	20	15	10	5	0
Total	100	100	100	100	100	100	100	100	100

[a] May be less than, but no more than the requirements given.

Discussion

Now we have cherry from five sites, six ways to cut up the boards (GCL's), and nine cutting bills. A rough-mill production run using cherry from any one of the five sites to make blanks needed for any cutting bill is preplanned. Linear programming (LP) was used to determine the minimum number of boards needed for each cutting bill from each site (Reynolds 1984). These minimal solutions—how many board feet are to be cut up per GCL for each cutting bill using cherry from each site—are shown in the Appendix.

As a preplanning example, consider using the Ludlow, Pennsylvania, cherry to make the blanks required by System 6. Table 13, Appendix, shows that 75 percent of all boards should be cut up using GCL1; 25 percent of all boards should be cut up by GCL4. The LP program output would show that for 10,000 square feet of blanks production, 22,075 board feet of boards would have to be used. Table 5 shows Ludlow, Pennsylvania, yields are 44.3 percent for GCL1 and 48.2 percent for GCL4. The total yield would be 45.3 percent ($44.3 \times .75 + 48.2 \times .25 = 45.3$). Using GCL1, 16,556 board feet of boards would be cut up. Using GCL 4, 5,519 board feet of boards would be cut up.

The results of the LP solutions are shown in Table 7. They were very good for cutting bills that required no more than 15 percent long blanks; that is, cutting bills 1 through 4 for Ludlow, Pennsylvania, and the other three similar sites. The Middle Mountain, West Virginia, site was very good for cutting bills that required no more than 30 percent long blanks; that is, cutting bills 1 through 7. Yields over 45 percent were considered very good.

As demand for long blanks increased, two things were apparent from the LP solutions: (1) more medium and short blanks were made than were needed; and (2) more salvage blanks were made than were permitted. Although they were good blanks, they were considered extra. Tables 8 and 9 show the percent yield considered extra in these categories.

When all the yields from Tables 7, 8 and 9 are added per site and cutting bill, a strange thing is apparent. The total yields shown in Table 10 are very consistent regardless of the cutting bill requirements. From this, we deduce that the six GCL's used permit sufficient flexibility within the System 6 rough mill to

Table 7.—Blank yields per cutting bill from each site

(In percent of board feet)

Site	Cutting bill								
	1	2	3	4	5	6	7	8	9
Ludlow, PA	44.8	45.5	46.0	46.8	35.8	38.7	33.4	29.5	26.2
Glen Hope, PA	43.7	45.0	45.4	45.2	34.2	36.6	31.6	27.7	24.6
Dushore, PA	44.6	45.2	45.5	46.4	37.4	40.2	34.4	30.4	27.0
Oakland, MD	44.7	45.4	45.9	46.4	36.1	33.7	30.8	28.3	26.5
M. Mountain, WV	51.8	52.3	52.7	53.1	53.2	49.9	43.4	38.7	34.4

Table 8.—Medium and short blank yields per cutting bill and site in excess of requirements

(In percent of board feet)

Site	Cutting bill[a]				
	5	6	7	8	9
Ludlow, PA	2.0	5.0	7.5	9.5	11.4
Glen Hope, PA	3.2	6.5	9.2	11.3	13.0
Dushore, PA	1.3	4.5	7.2	9.2	11.3
Oakland, MD	1.6	4.5	7.0	9.3	11.1
M. Mountain, WV	0.0	2.0	4.8	7.5	9.9

[a] No excess of requirements for cutting bills 1-4.

get consistently encouraging yields. In other words, changing the cutting bill does not lower yield, it just means that extra blanks are made at that time.

The LP solution gives the board quantity to be cut up using each GCL. The rough mill is run and the blanks are made until all the boards to be cut have been used. Then the longer blanks in excess of requirements are trimmed to meet the shortages in shorter blanks. Board cutup and blank trim are considered within the LP run. The amount of longer blank trimming per cutting bill is shown in Table 11 for each site.

The figures in Table 11, per cutting bill, are remarkably consistent. The quantity of longer blanks trimmed to fulfill the shorter blank requirements is similar for each cutting bill, though the Middle Mountain site cherry board grade distribution is different from that of the other four sites. The LP technique is able to make compensation for the various input board grade differences from each site.

The differences in board qualities from each site can be compensated for through the judicious balancing of the quantities of boards to be cut up using each GCL. However, these compensations have a limit. When demand for long blanks exceeds 15 percent (cutting bills 5 through 9), yields in required blanks drop though total yield of blanks in all lengths remains high.

Table 9.—Salvage blank yields per cutting bill and site in excess of permitted quantities

(In percent of board feet)

Site	Cutting bill[a]				
	5	6	7	8	9
Ludlow, PA	8.4	2.5	4.6	6.6	8.0
Glen Hope, PA	7.8	1.6	3.8	5.7	7.0
Dushore, PA	8.6	2.5	5.0	7.1	8.4
Oakland, MD	8.3	2.2	4.4	6.2	7.7
M. Mountain, WV	0.0	0.7	3.6	5.8	9.7

[a] No excess of permitted quantities for cutting bills 1-4.

Table 10.—Total yield of blanks per cutting bill and site

(In percent of board feet)

Site	Cutting bill								
	1	2	3	4	5	6	7	8	9
Ludlow, PA	44.8	45.5	46.0	46.8	46.2	46.2	45.5	45.6	45.6
Glen Hope, PA	43.7	45.0	45.4	45.2	45.2	44.7	44.6	44.7	44.6
Dushore, PA	44.6	45.2	45.5	46.4	47.3	47.2	46.6	46.7	46.7
Oakland, MD	44.7	45.4	45.9	46.4	46.0	40.4	42.2	43.8	45.3
M. Mountain, WV	51.8	52.3	52.7	53.1	53.2	52.6	51.8	52.0	54.0

Table 11.—Trimming of longer blanks to fulfill shorter blank requirements

(In percent of square feet of blank requirements)

Site	Cutting bill								
	1	2	3	4	5	6	7	8	9
Ludlow, PA	35.8	26.5	17.9	8.2	6.4	3.0	2.5	4.9	4.0
Glen Hope, PA	33.7	23.8	15.4	7.2	4.5	3.3	3.6	4.6	5.7
Dushore, PA	36.8	27.4	18.8	9.8	7.6	3.7	4.5	4.7	3.7
Oakland, MD	35.0	24.3	14.9	8.8	4.8	3.4	2.6	3.4	2.6
M. Mountain, WV	36.9	26.0	16.0	9.5	5.4	7.3	7.2	6.5	6.9

Economics

A new System 6 mill requires an initial capital investment of roughly $2 million plus $200,000 of working capital. We will consider a 16 Mbf (thousand board feet) per shift input mill (Hansen and Reynolds 1984) with a 15-percent increase in machinery prices from mid-1981. We believe that a successful blanks business would require at least a 20-percent IRR (internal rate of return) after taxes.

Sawmillers can buy small-diameter, low-grade cherry logs and bolts at $100 per Mbf international 1/4-inch scale, no scaling deductions used. This is equivalent to $45 per cord. Experience with small sawmillers has shown that sawing bolts to cants at $50 per Mbf is profitable. A thousand board feet of bolts equals 1,000 board feet of cants as cants are the only products made and no overrun is considered. At $30 per Mbf for hauling, the f.o.b. (free on board) System 6 plant cant price is $180 per Mbf. The System 6 mill manager will be assured of a cant supply at this price.

Rough-dimension parts are conventionally made by purchasing No. 1 Common or Better lumber, kiln drying the lumber, then rough milling it to parts. There are no parts pricing reports, though there are hardwood lumber price reports. In 1984, Appalachian black cherry, 4/4 thickness, No. 1 Common grade, had a $600 Mbf average price. We feel that this green lumber price will dictate a $2.50 per square foot average selling price for 4/4 cherry rough-dimension parts. We allowed a 12-percent discount for converting blanks to parts and arrived at the $2.20 per square foot average price for 4/4 C1F blanks.

When cherry from the three Pennsylvania sites and the Maryland site is used to meet the normal demand for blanks, the average yield would be 45 percent. If all the blanks produced were sold at the average price of $2.20 per square foot, the rate of return would be approximately 39 percent. The operating costs, revenues, and investments are shown in Table 12. When cherry from the West Virginia site is used, the yield averages 53 percent, and the rate of return is about 50 percent.

Table 12.—Annual operating costs and revenues

(CIF blanks from all sites except Middle Moutain and all blanks sold)

Item		Year 1*	Years 2–10
Costs: Variable			
Cants 180/Mbf × 16 Mbf/shift × 240 shifts/year		$ 346,000	$ 691,000
Labor 45 men @ $6.60/hr + 2 men @ $11/hr	$638,000		
Supplies	57,000		
Utilities	76,000		
Total: Other Variable Costs	$771,000	$ 386,000	$ 771,000
Sales costs (5% sales)		95,000	190,000
Costs: Fixed			
Management and administrative	85,000		
Insurance	48,000		
Maintenance	160,000		
Total: Fixed Costs	$293,000	$ 293,000	$ 293,000
Costs: Total		$1,120,000	$1,945,000 (51% of sales)
Revenues:			
CIF blanks at 45% yield and $2.20/sq ft			
3,840,000 bd ft cants × 0.45 = 1,728,000			
Sq ft blanks × 2.20 = 3,802,000		$1,901,000	$3,802,000

*During the first year, only half the annual production will be made.

Capital Investment:	Land	$ 100,000
	Machinery	900,000
	Kilns and boilers	700,000
	Buildings	300,000
	Working capital	200,000
	Total	$2,200,000

The demand for long blanks is an important production problem. When long blanks are limited to the normal 15 percent of total output, the production controls can function efficiently with wood from all sites and return on investments will be very good. When the Middle Mountain cherry is used, long-blank production can be allowed to rise to 25 percent of total output without negatively affecting return on investment.

When long-blank requirements rise above 15 percent (25 percent for Middle Mountain cherry), yields in required blanks decrease and income may fall. One way to possibly alleviate this problem is to increase prices for the long blanks raising income to the required level. A companion paper has been written to study this problem in detail (Reynolds and Hansen, 1986). We found that by chipping some of the poorest boards, buying additional cants to keep the production level constant, and selling the extra short blanks at reduced prices, the surcharge for long blanks could be kept low. For cutting bill 9 (40 percent long blanks), the surcharge needed was only 18 percent over normal blank price. When blank customers are willing to pay substantial surcharges for long blanks, opportunities for additional profits rise.

Conclusions

Opportuni*ies are available for foresters, sawmillers, dimension plants, furniture makers, and kitchen cabinet companies by utilizing the small-diameter cherry. Small-diameter bolts from cherry thinning and first commercial cuts prescribed under the best silvicultural practices can be utilized profitably. Sawmillers can make System 6 cants for profitable sale rather than sawing and trying to sell the No. 2 Common and poorer lumber. Dimension plants, using System 6 technology, can buy cants and make blanks and earn competitive returns. Furniture and kitchen cabinet companies can buy blanks, or make them themselves, for the manufacture of fine solid cherry offerings. The opportunity for using cherry to make informal furniture is very intriguing.

After we had completed our cherry studies, we contacted furniture companies in Pennsylvania and North Carolina and asked them for cutting bills for some of their furniture. Using the blanks we had made, we made rough-dimension parts that they included in regular production runs. In all instances, the parts we furnished were equal in quality and acceptability to their own parts. Consequently, we do not hesitate to recommend the use of small-diameter, low-grade cherry with System 6 to make blanks for furniture and kitchen cabinet products.

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APPENDIX

Table 13.—Minimal board input solutions for Ludlow, Pennsylvania, cherry

(Percent input board feet to be cut up by each GCL)

Cutting bill	GCL 1	2	3	4	5	6	Total
1	75	0	0	25	0	0	100
2	68	0	0	32	0	0	100
3	63	0	0	36	0	0	100
4	31	0	64	5	0	0	100
5	7	17	43	0	32	0	100
6	8	15	31	0	46	0	100
7	10	14	9	0	66	0	100
8	0	23	0	5	72	0	100
9	4	21	0	5	70	0	100

Table 14.—Minimal board input solutions for Glen Hope, Pennsylvania, cherry

(Percent input board feet to be cut up by each GCL)

Cutting bill	GCL 1	2	3	4	5	6	Total
1	74	0	0	26	0	0	100
2	67	0	0	33	0	0	100
3	62	0	0	38	0	0	100
4	29	0	70	1	0	0	100
5	40	0	60	0	0	0	100
6	58	0	42	0	0	0	100
7	67	0	25	0	7	0	100
8	59	0	38	0	3	0	100
9	60	0	38	0	2	0	100

Table 15.—Minimal board input solutions for Dushore, Pennsylvania, cherry

(Percent input board feet to be cut up by each GCL)

Cutting bill	GCL 1	2	3	4	5	6	Total
1	78	0	0	22	0	0	100
2	71	0	0	29	0	0	100
3	62	0	8	30	0	0	100
4	46	0	37	17	0	0	100
5	10	13	52	0	25	0	100
6	11	7	47	0	34	0	100
7	12	5	38	2	43	0	100
8	12	35	0	53	0	0	100
9	9	10	34	0	47	0	100

Table 16.—Minimal board input solutions for Oakland, Maryland, cherry

(Percent input board feet to be cut up by each GCL)

Cutting bill	GCL 1	2	3	4	5	6	Total
1	72	0	0	28	0	0	100
2	65	0	0	35	0	0	100
3	52	0	0	36	12	0	100
4	22	0	26	21	29	2	100
5	0	12	49	0	39	0	100
6	0	17	29	0	54	0	100
7	5	15	0	9	71	0	100
8	12	35	0	53	0	0	100
9	0	22	0	5	73	0	100

Table 17.—Minimal board input solutions for Middle, Mountain, West Virginia, cherry

(Percent input board feet to be cut up by each GCL)

Cutting bill	GCL 1	2	3	4	5	6	Total
1	0	0	49	7	0	44	100
2	0	0	49	12	0	39	100
3	0	0	53	13	0	34	100
4	0	0	72	5	0	23	100
5	0	0	80	3	4	13	100
6	0	0	75	0	25	0	100
7	0	0	22	10	68	0	100
8	0	0	0	16	84	0	100
9	0	0	0	15	85	0	100

Reynolds, Hugh W.; Hansen, Bruce G. **Making black cherry blanks from System 6.** Res. Pap. NE-574. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1986. 10 p.

Low-grade, small-diameter black cherry *(Prunus serotina)* timber was used to make System 6 cants. Cherry from the Allegheny National Forest (Ludlow, PA), west-central Pennsylvania (Glen Hope, PA), north-central Pennsylvania (Dushore, PA), western Maryland (Oakland, MD), and the Monongahela National Forest (Middle Mountain; WV) was used. The cants were resawed to 4/4 boards, the boards dried, and blanks were made at the Princeton Laboratory's System 6 pilot plant. By varying the rough mill procedures, differences in board quality and cutting bill requirements were accommodated keeping yields high. The cherry from the Pennsylvania and Maryland sites gave similar yields, while the West Virginia cherry gave 5 percent higher yields. Gum streak was not a problem. Pennsylvania and Maryland cherry gave a 39.0 percent return, and West Virginia cherry gave a 50.3 percent return on a $2.2 million 10-year investment.

ODC 836.1; 847.1/2

Keywords: Low-grade utilization, hardwood dimension.

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*U.S. GOVERNMENT PRINTING OFFICE: 1986-605-026;20039

United States
Department of
Agriculture

Forest Service

**Northeastern Forest
Experiment Station**

Research Paper
NE-575

1986

Anatomy of Backcountry Management Costs

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Manuscript received for publication 3 June 1985

Abstract

Operation and management costs for several dispersed overnight site locations and backcountry trails in the White Mountain National Forest were studied. Average annual costs ranged from $200 to $1,500 per mile for trails and from $0.35 to $4.29 per visitor for overnight sites. Average annual costs for trails and overnight sites increased with elevation and use levels, but on a per-visitor basis, high-use trails cost less to maintain than low-use trails at all elevations. Costs per visitor at overnight sites were less well defined. The method used in this study may be useful to backcountry recreation managers in their efforts to acquire a better understanding of all the costs of providing backcountry recreation opportunities.

What's the Problem?

Dispersed recreation is the most prevalent use of national forests, and backcountry hiking and camping are among the most popular activities. Before the 1960's, relatively few people ventured into remote forest lands seeking wilderness or backcountry recreation experiences, and management needs were few. However, during the 1960's and early 1970's, visitation increases of 15 percent per year at overnight sites were common. Spencer and others (1980) noted a threefold increase in hiking and backpacking between 1965 and 1977, but felt that the rate of increase had declined between 1977 and 1980. From 1981 to 1984, total dispersed recreation in the National Forest System actually dropped from 151 to 145 million visitor-days.

However, these 20 years of heavy use have had an impact. Many trailheads have been expanded and in some cases paved to accommodate increased use. Trails have been reconstructed to reduce soil erosion and to provide easier and safer access to remote destinations. Overnight sites have been developed to reduce the physical impacts of camping as well as provide shelter and other amenities for overnight visitors. These improvements cost money, and annual maintenance must continue every year. Someone must bear these costs—usually the public land management agency or a trail-maintaining club.

The study of backcountry management costs is not a new endeavor. Tyre (1975) found that average costs in the southeastern United States ranged from $0.07 per visitor-day on general, undeveloped lands to $0.27 per visitor-day on wilderness areas. Guldin (1980) compared 1977 wilderness management costs on four areas in New England and found area costs of $1.80 to $8.37 per visitor-day. (These costs included payments in lieu of taxes, fire protection costs, and planning costs.) And, Irland (1980) stated that management costs on four different backcountry areas in Maine ranged from $1.36 to $4.98 per visitor-day. In each of these studies, opportunity costs were not included.

These studies have contributed to a better understanding of the fixed costs associated with providing backcountry and wilderness recreation opportunities. But, other important dimensions remain. The variable costs of specific facilities on different land types with different levels of use have not been investigated. In this paper, costs affected by these variable factors of backcountry management are examined. Because of the variation in terrain characteristics and trail locations within the eastern mountain regions, trail and overnight facility requirements might be expected to vary significantly with use levels.

To accommodate these variations, a framework was developed for relating the costs of providing backcountry hiking and camping opportunities to use levels and physical site characteristics: Recreation use levels—volume, fequency of use, and time of season—and physical site characteristics—topography, soil drainage, and plant community—require management actions to protect resources. These resources—structures, use management programs, and design techniques—incur management costs that vary with labor costs, material costs, transportation costs and administrative overhead. This framework can be easily integrated into the Design Capacity System introduced by Leonard and others (1977), which is influenced by the recreational objectives that management sets for an area, the physical ability of the area to fulfill the objectives, the financial resources available, and the social constraints that may be imposed by users.

In the White Mountain National Forest of New Hampshire, backcountry facilities are located on a variety of terrains with varying suitabilities for recreational use. The physical impact of hiking and camping tends to be concentrated on small portions of the recreation lands, mainly along trail corridors and at overnight sites. In this study, we investigated the types of management practices adopted for trails and overnight sites on various forest areas and the costs associated with those practices. Our primary interest was to compare the costs incurred for resource protection on various sites with different physical characteristics and use levels. Costs of land acquisition, fire protection, search and rescue operations, and off-site visitor information programs were not included.

Study Areas

The backcountry areas used for this study are composed of a mixture of granite and metamorphic gneiss and schists. Past glacial activity and the humid climate have weathered the White Mountains down to rounded land forms and produced four principal kinds of surface deposits: 1) angular boulders with little soil; 2) colluvium with shallow, weakly developed soils; 3) glacial till deposits of varied depths of rock and sediments; and 4) outwash soils.

The lower valley floors and toeslopes located at elevations generally below 2,300 feet are characterized by smooth terrain with deep, well-drained soils of cobbly, loamy sand or bouldery, sandy loam. The midslopes are characterized by a variety of glacial till deposits. The soils are generally deep, but surface drainage varies from slow to rapid, depending on the presence of shallow, hardpan layers, the distribution of subsurface boulders, and terrain undulations and rockiness. The upper elevation land types, generally occurring above 3,000 feet, have shallow soil with many angular boulders and bedrock or ledge frequently exposed to the surfaces. Above 4,200 feet the soils become very shallow and the climate severe. The vegetation changes from low, softwood forest to krummholz to alpine tundra; and, finally to rocky summits with no soil or alpine vegetation.

Study Method

A variety of trail segments and overnight sites were investigated to determine what types and amounts of improvements had been made. Sites were selected to provide a broad representation of land types, trail grades, and use levels.

About 75 miles of trail segments were examined on six different land types, ranging from hardwood forests on lower mountain slopes to alpine tundra on upper mountain slopes. Three trail grade classes (0 to 15 percent, 15 to 30 percent, and greater than 30 percent) were chosen to further divide trail maintenance needs within each land type. Daily trail use was estimated by managers and used to classify trail segments into four use-level groups (low—less than 10; moderate—10 to 30; high—30 to 100; and very high—greater than 100 persons per day). For purposes of a more manageable framework, the land types and trail grade classes were collapsed and combined into three categories—low elevation and low trail grades; mid-elevation and moderate trail grades; high elevation and steep trail grades. Trail use levels were also combined to low use (500 visitors per year) and high use (6,500 visitors per year). This resulted in each trail segment being placed in one of six categories.

For each trail category, trail maintenance structures (waterbars, steps, bridging and puncheon, side-hill cribbing, and so on) were counted, and the length of trail sections in need of maintenance was measured. Trail sections were considered problems if they had: 1) severely eroded sections (sections with gullies greater than 6 inches deep or with very loose, unstable soil on a steep grade) for more than 10 feet; 2) side-hill erosion from drainage crossing the trail; 3) poorly drained sections on flat areas that were greater than 10 feet long or that were causing trail widening problems. This inventory defined the number of improvements made in each trail category, and where necessary, the number of improvements required on problem sections to bring the trail up to management standards. The average number of improvements needed per mile of trail was computed by adding the number of improvements determined to be needed for each trail category and then dividing by the total length of trail observed in that category.

About two dozen overnight sites were classified into 12 site conditions, represented by three different land types and four different use levels. The use levels represented the capacities for which the sites had been designed and built. Low-use sites can accommodate 2 to 4 persons per night (200/year); moderate-use sites can accommodate 4 to 8 persons per night (600/year); high-use sites consist of shelters and/or tent platforms and can accommodate about 20 people per night (1,500/year); and very high-use sites have several shelters and tent platforms that can accommodate 50 to 60 people per night (3,000/year).

The management needs for each site condition were determined from observations of the practices adopted at well-managed sites. Where soil conditions dictated some form of human-waste disposal other than a pit privy, bin composting was chosen over a haul-out system. The Appalachian Mountain Club hut facilities were not included in this study because they are managed like hotels offering bedding and hot meals, rather than backcountry campsites.

Management costs for reconstruction and maintenance of trails and overnight sites were computed using a set of standard unit prices for each management structure and program. Standard unit prices were used for two reasons: records of actual expenditures for backcountry maintenance work were not available for the type of categories desired; and a comparison of actual costs would have confounded the results due to the great variation of costs for items such as labor, transportation, and materials. By calculating the costs with standard unit prices, we were able to compare the relative difference in costs between site and use-level conditions.

Estimates of unit prices for various trail maintenance jobs and overnight facilities were obtained from the Green Mountain National Forest in Vermont, the White Mountain National Forest in New Hampshire, and the Appalachian Mountain Club. For some of the overnight facilities, standard costs were calculated from itemized expense needs to which unit prices for labor, construction materials, travel, and overhead were applied. The unit prices used in this study are listed in Tables 1 and 2.

Table 1.—Trail construction and maintenance costs, in dollars

Item	Unit cost[a]
A. Trail construction	
1. Clearing	1,742/mile (0.33/linear foot)
2. Waterbars	16.50/waterbar
3. Ditching	1.65/linear foot
4. Steps—rock	15.10/step
—log	16.15/step
5. Cribbing—rock	9.45/linear foot
—log	5.85/linear foot
6. Puncheon (bridging)	
native	4.85/linear foot
7. Rock tread	
stepstones (1 step/2 feet)	2.10/linear foot
paving (all rock)	4.90/linear foot
8. Scree walls	2.00/linear foot[b]
9. Special provisions	
pin step	28.00/step[b]
cut step or ladder used on steep rock faces	45.00/step or ladder
B. Trail location markers	
1. Paint blazing	31.50/mile
2. Cairn building	
a. large, every 50 feet	10.40/cairn[b]
b. small, every 100 feet	2.60/cairn[b]
C. Trail maintenance	
1. Patrolling—every year	10.40/mile
clear blowdowns	
clean out drainage ditches	
2. Brushing—every 3 years	
a. low elevation (deciduous forest)	52.00/mile including patrolling
b. mid-elevation (softwood forest)	104.00/mile, including patrolling

[a] Most unit costs are based on Green Mountain National Forest co-op prices for 1979. Costs include 10 percent overhead.

[b] Appalachian Mountain Club estimates of labor times were used to compute unit costs for these items.

Table 2.—Overnight site facility and management program costs, in dollars

Category	Occurrence	Unit cost[a]
A. Facility		
1. Tent platforms	10 years	656.00/platform
Double size (10 ft × 12 ft)		
2. Shelter, 3-sided & precut		
Capacity 8	Every 20 years	6,555.75
3. Shelter, 3-sided & precut		
Capacity 10 to 14	Every 20 years	8,741.00
4. Special water supply and		
dishwashing areas	10 years	56.00
5. Signs	Replacements needed every 5 years	15.00/sign
6. Human-waste disposal facilities		
Outhouse and pit	20 years	610.00
Move outhouse to new pit	Depends on site use and soil conditions	160.00
7. Bin composting system		
Outhouse—modified for compost system	20 years	840.00
8. Equipment for 1 unit (max. 1,500 visitors/year	5 years	330.00/unit
Operating costs		
1-unit system	Annually	438.00
1-unit system at caretaker site	Annually	40.00
2-unit system	Annually	873.00
2-unit system at caretaker site	Annually	60.00
B. Management Program		
1. Caretaker programs		
a. Full-time, long season with law enforcement capability (Total—164 man-days)	Annually	10,899.00
b. Full-time, long season with no law enforcement capability	Annually	8,833.00
c. Full-time, no law enforcement capability (Total—98 man-days)	Annually	5,506.00
d. Peak-use, no law enforcement capability (Total—30 man-days)	Annually	1,764.00
2. Annual site maintenance programs (includes labor and materials for structure repairs)		
a. Patrolling only (at tentsite areas—3 trips/year)	Annually	42.50
b. Level I (at low-use sites, privy only)	Annually	138.60
c. Level II (at moderate-use sites) with no caretaker available	Annually	337.00
If at caretaker site, caretaker program costs cover most labor needs	Annually	200.00
d. Level III (at high-use or more structured sites)		
No caretaker available	Annually	674.00
If at caretaker site	Annually	400.00

[a] Includes labor costs (based on 1977 USDA Forest Service rates), material costs, transportation costs, and a 26 percent administration overhead cost.

The unit prices were applied to each of the reconstruction and maintenance jobs that would be required each year over a 20-year period. The lifetimes of the trail structures are not known, so an assumption was made that half of the structures would need replacement every 10 years. The cost per visitor per year was calculated as the average annual cost divided by an average number of users per year. An example of the cost calculations for one trail section is shown in Table 3.

Table 3.—Example of average annual cost calculations (AC), in dollars, for a trail at mid-elevation, of moderate (15-30%) grade, and with high use.

Year	Initial construction (C_o)	Unit cost	Cost/mile
0	Clearing & grubbing	1,742.00/mile	1,742.00
	Blazing	31.50/mile	31.50
	Structures:		
	steps (32)	15.10/step	483.20
	cribbing (28 ft)	5.85/lin ft	163.80
	waterbars (56)	16.50/waterbar	924.00
	ditching (13 ft)	1.65/lin ft	21.45
	Tread:		
	rock paving (30 ft)	4.90/lin ft	147.00
	log bridging (17 ft)	4.85/lin ft	82.45
		Total C_o =	3,595.40

Year	Maintenance costs (C_m)	Cost/mile
1	Patrolling	10.40
2	Patrolling	10.40
3	Brushing, patrolling, blazing ($104.00 + $31.50)	135.50
4	Patrolling	10.40
5	Patrolling	10.40
6	Brushing, patrolling, blazing	135.50
7	Patrolling	10.40
8	Patrolling	10.40
9	Brushing, patrolling, blazing	135.50
10	Patrolling	10.40
	Replace 1/2 C_o structures	910.95
	Total C_m =	1,390.25

$AC = (C_o + C_m) \div Y$
$= (\$3,595 + \$1,390) \div 10$
$= \$498.50$
Cost/visitor/year = $498.50 ÷ 6,500 = $0.08
Y = 10 years

What We Found

Trails

On low-elevation trails with low use and grades less than 15 percent, we observed no maintenance structures or trail problems. On similar trails receiving high use, a moderate amount of erosion control work had been done and some tread (rock paving or wood puncheon) had been used on flat, poorly drained areas. The calculated average annual costs for a 20-year period ranged from $210 per mile on low-use trails to $574 per mile on high-use trails (Table 4).

As previously stated, trail data were combined for the mid-elevation land types because of the complex variability in surface drainage conditions and trail grades. Trail improvements were few for low-use trails of moderate grade, and the calculated costs were similar to those on the low-elevation trails. On high-use trails, more trail structures were installed for erosion control and poorly drained areas. The calculated average annual cost was about twice that of the low-use trails. One of the most expensive trails was on a poorly drained basin floor beneath a cirque headwall in one of the mid-elevation land types. The trail was on a low grade and designed for very high use with extensive rock tread and wood puncheon. The calculated annual cost was $2,700 per mile.

The calculated average annual costs for steep-grade trails in the upper elevation, softwood forest ranged from $291 to $1,508 per mile. The low-use trail sections had little work, while the high-use trail sections had extensive erosion control work and were much more expensive to maintain.

In general, all the low-use trails, regardless of location, had the lowest costs, but because of fewer trail users, the costs per visitor were higher than those of the higher use trails. Trails with the most extensive work were those receiving high to very high use and were located in upper elevation, softwood forests over flat, poorly drained areas or on steep grades. Tundra trails also had extensive work and high costs if they were receiving high use. Tundra trails with low to moderate use, however, had annual costs that were lower than those for trails in the low-elevation hardwood forests.

Table 4.—Trail maintenance structures and calculated costs.

Trail location and grade	Structures and costs/mile	
	Low use (500 visitors/year)	High use (6,500 visitors/year)
Low elevation, hardwood forest, deep, well-drained soils—low trail grade	No structures C_o = $1,773[a] C_m = $32[a] AC = $210[a] ($0.42/visitor)	Waterbars—124 Steps—6 Tread—44 ft Scree—40 ft C_o = $4,200 C_m = $154 AC = $574 ($0.09/visitor)
Mid-elevation, mixed hardwoods-softwoods; soil drainage variable, bouldery terrain—moderate trail grade	Waterbars—3 C_o = $1,823 C_m = $50 AC = $233 ($0.47/visitor)	Waterbars—56 Steps—32 Cribbing—28 ft Ditching—13 ft Tread—47 ft C_o = $3,595 C_m = $139 AC = $499 ($0.08/visitor)
Upper-elevation, softwood forest; thin soils, bouldery terrain—steep trail grade	Steps—26 Waterbars—3 C_o = $2,216 C_m = $70 AC = $291 ($0.58/visitor)	Steps—420 Waterbars—98 C_o = $9,733 C_m = $535 AC = $1,508 ($0.23/visitor)

[a] C_o = Initial construction cost, including clearing and blazing
C_m = Average annual maintenance cost
AC = Average annual cost (See Table 3 for calculations)

Overnight Sites

The management practices that have been used for resource protection at designated overnight sites receiving clustered use include: 1) shelters or tent platforms to concentrate camping parties and reduce the surface area that becomes trampled and compacted; 2) a human-waste disposal system that does not rely on soil leaching; 3) delineated paths within the overnight site to discourage indiscriminate trampling of ground vegetation; 4) a drinking-water outlet pipe at a "hardened" collection point (this has been used to protect the ground surrounding a spring outlet, especially where frequent trampling could cause soil to wash into the water supply); and 5) resident caretakers to provide visitor information, maintain site facilities, operate compost systems, and where necessary, police the site. Routine maintenance is also required, including litter removal, shelter and privy cleaning and repairs, and sign replacement. At sites with caretakers, most of the routine maintenance jobs are handled without additional labor costs.

The calculated average annual costs (AC) of designated overnight camping areas ranged from $74 to $12,577 (Table 5). These costs were computed by adding the initial construction costs (C_o) to 19 years of average annual maintenance costs (C_m), which include replacement costs for facilities with less than a 20-year life and management program costs (see Table 2B), and dividing the sum by 20 for an average annual cost. The higher costs were required for areas designed for higher use or at higher elevations. These hypothetical costs represent costs that would be required to reconstruct and maintain the on-site facilities and management program adopted primarily for resource protection at various camping areas in the White Mountains. The costs per visitor are based on an average number of visitors per year that typically use the site.

Table 5.—Overnight site costs, in dollars, by use levels

Site location	Use levels (persons/year)			
	Low (200)	Moderate (600)	High (1,500)	Very high (3,000)
Low-elevation mountain slopes; hardwood forests; deep, well-drained soils on smooth terrain	Designated dispersed tentsites (4) C_o = 484[a] C_m = 52 AC = 74 (0.37/visitor)	Tentsites (Cap. 4) C_o = 1,387 C_m = 149 AC = 211 (0.35/visitor) Shelter (Cap. 8) C_o = 7,458 C_m = 370 AC = 724 (1.28/visitor)	Shelter & platforms (Cap. 20) C_o = 9,710 C_m = 2,273 AC = 2,645 (1.76/visitor)	Shelter & platforms (Cap. 60) C_o = 22,770 C_m = 12,040 AC = 12,577 (4.19/visitor)
Mid-elevation mountain slopes; mixed hardwood-softwood forest; soil drainage variable on undulating terrain	Designated dispersed tentsites (4) C_o = 484 C_m = 52 AC = 74 (0.37/visitor)	Tentsites (Cap. 4) C_o = 1,916 C_m = 636 AC = 700 (1.17/visitor) Shelter & platforms (Cap. 12) C_o = 8,810 C_m = 875 AC = 1,272 (2.12/visitor)	Shelter & platforms (Cap. 20) C_o = 10,543 C_m = 2,655 AC = 3,049 (2.03/visitor)	Shelter & platforms (Cap. 44) C_o = 17,309 C_m = 9,696 AC = 10,076 (3.36/visitor)
Upper-elevation mountain slopes; softwood forest; rapid to poorly drained, thin soils on bouldery terrain	Designated dispersed sites (4) C_o = 484 C_m = 177 AC = 192 (0.96/visitor)	Tent platforms (Cap. 10) C_o = 3,240 C_m = 2,305 AC = 2,352 (3.92/visitor) Shelter & platforms (Cap. 12) C_o = 8,838 C_m = 2,245 AC = 2,575 (4.29/visitor)	Shelter & platforms (Cap. 20) C_o = 10,375 C_m = 6,101 AC = 6,314 (4.21/visitor)	Shelter & platforms (Cap. 44) C_o = 17,450 C_m = 9,696 AC = 10,083 (3.36/visitor)

[a] C_o = Initial construction cost.
C_m = Average annual maintenance cost, based on 19 years, including replacement costs for facilities of less than a 20-year life.
AC = Average annual cost = $(C_o + 19\,C_m) \div 20$

The construction and annual maintenance costs rose more quickly for upper elevation, softwood sites than for lower elevation sites because of the need for a human-waste disposal system, added ground protection measures, and a caretaker program. Sites with the lowest average costs per visitor are the low-use sites that do not require facilities for ground protection or human-waste disposal. The site with the highest cost per visitor ($4.29) is an upper elevation location that could receive moderate use of about six to nine persons per night. At these use levels, several management facilities are needed, but the additional costs are not spread over a large number of visitors.

The sites with the highest average annual costs are the large sites designed for very high use. These sites tend to attract many inexperienced or inconsiderate visitors. They require full-time caretakers with law enforcement responsibilities plus most or all of the structural facilities needed at other locations. The low-elevation sites (AC = $12,577) have the added problem of close proximity to trailheads. Their high construction costs compounded by very high maintenance costs results in very high costs per visitor.

Discussion

Public agencies are being asked to do more every year with fewer dollars. Furthermore, this year's dollar does not go as far as last year's, and next year some recreation and park agencies may be asked to become more self-sufficient. How can the information in this paper help planners and managers meet this financial pinch? Before an agency can meet a financial pinch, it should know what its costs are. The operation and maintenance (O&M) costs of providing backcountry recreation opportunities in northern New England were computed using a cost-per-visitor mile and cost-per-visitor night framework that should not be too difficult to adopt in other locations. Based on use levels and land characteristics, and influenced by management's objectives, our study allows disaggregation of the costs of provision down to types of sites.

For example, the data in Table 5 show that "very high-use" sites at all elevations are extremely expensive to build and maintain, both in total dollars expended and in costs per visitor, when compared to costs of provision for sites that accommodate lower use levels. It also shows that upper elevation sites are very expensive to manage at almost all use levels. If the costs per visitor-night of these expensive or popular sites are to be controlled, then use levels of those sites should not be allowed to rise. This goal might be attained by issuing permits prior to a party's departure for expensive or popular sites and/or charging a "cost of provision fee" for the permit.

The framework we used to collect trail data was too detailed. Although use data were initially collected for four levels of trail use and on six different land types and at three trail grade classes, we combined the data into two use levels at three grade classes, with the grade classes encompassing the land types.

Managerial decisions based on the cost-per-visitor mile may not be quite as cut and dried as those based on costs-per-visitor night because as use rises, the per-unit costs go down. Operation and maintenance costs averaged about $0.50 per visitor-mile on low-use trails and about $0.10 on high-use trails except at upper elevations where the costs rose to $0.23 per visitor-mile. Perhaps a framework containing only six categories—two use levels at three elevation-grade levels—is enough detail for decisionmaking.

If visitor fees are adopted for backcountry recreation, knowledge of the management costs for different types of opportunities could be useful in determining fee schedules for different types of areas rather than charging all visitors the same fee. Visitors to low-use, low-maintenance areas may resent having to pay the same fee as visitors to high-maintenance areas offering more facilities. With the heightened attention on public expenditures, this would seem the time to start a standardized and regular monitoring system for backcountry recreation management costs.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1986-605-026:20041

Echelberger, Herbert E; Plumley, Harriet J. **Anatomy of backcountry management costs.** Res. Pap. NE-575. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1986. 8 p.

Operation and management costs for several dispersed overnight site locations and backcountry trails in the White Mountain National Forest were studied. Average annual costs ranged from $200 to $1,500 per mile for trails and from $0.35 to $4.29 per visitor for overnight sites. Average annual costs for trails and overnight sites increased with elevation and use levels, but on a per-visitor basis, high-use trails cost less to maintain than low-use trails at all elevations. Costs per visitor at overnight sites were less well defined. The method used in this study may be useful to backcountry recreation managers in their efforts to acquire a better understanding of all the costs of providing backcountry recreation opportunities.

ODC 907.2:671:627.3

Keywords: backcountry, management, costs

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